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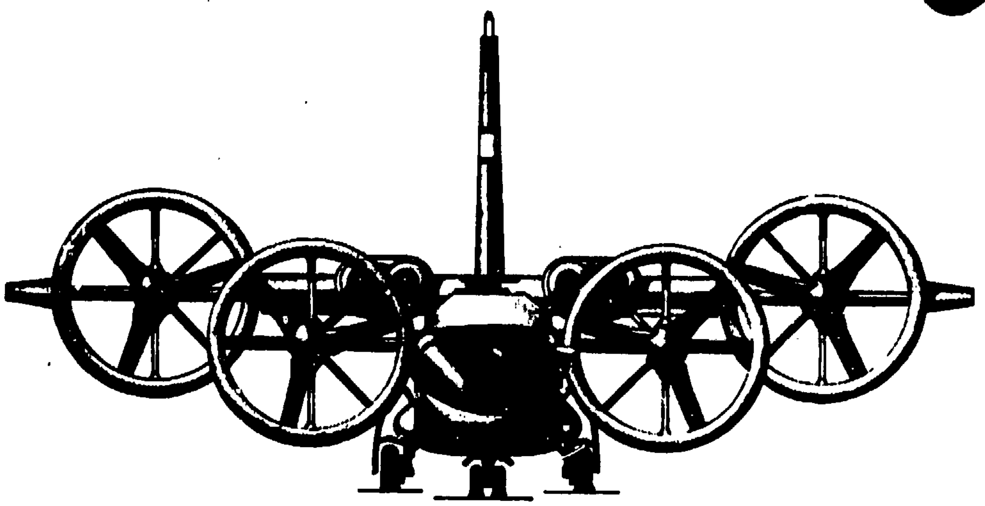
AN EXPERIMENTAL INVESTIGATION OF VTOL FLYING QUALITIES REQUIREMENTS FOR SHIPBOARD LANDINGS

Final Report

August 1981

by

Robert C. Radford
Dominick Andrisani II
John L. Beilman



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This fifth simulation experiment, using the U.S. Navy X-22A variable stability V/STOL aircraft, was undertaken to generate data for the development of flying qualities and advanced flight control system design criteria for the visual shipboard landing task. Since a broad range of flying qualities were simulated, actual landings were not performed because of flight safety considerations. Instead, a discrete three-dimensional position tracking task, presented to the pilot on a Head-Up-Display (HUD),

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was devised to evoke pilot control and stabilization activity similar to that in the actual shipboard environment. A microwave landing system with precision ranging capability served as the guidance sensor for both the translational rate flight control system mechanizations and for the HUD tracking information. A total of 111 evaluations were performed of various horizontal and vertical translational rate flight control system dynamics. The primary results of the program defined regions of satisfactory and acceptable flying qualities as functions of velocity command gain and the time constant of velocity response. The limits on command gain and time constant for satisfactory flying qualities indicated by this experiment are considerably smaller than those determined in ground simulator experiments.

FOREWORD

This report was prepared for the United States Naval Air Development Center under Contract Number N62269-78-C-0043 by Calspan Corporation, Buffalo, New York, and documents the research program performed under that contract during the period April 1978 to December 1980.

The flying qualities experiment reported herein was performed by the Flight Research Department of Calspan. Mr. J. L. Beilman was the Program Manager. Mr. R. C. Radford was the Project Engineer and Mr. D. Andrisani II was the Research Engineer; Mr. T. J. Gavin was the Project Engineer for the electronic systems, both airborne and ground-based. Technical monitoring was provided by the Naval Air Development Center; the authors wish to acknowledge their appreciation to Messrs. J. W. Clark, Jr., B. J. Gajkowski and C. Mazza of NADC for their support, and to Lt. J. C. Cumming, U.S.N. for his efforts in the development and validation of the simulation task.

Research programs using the X-22A aircraft are dependent on the collective contributions of a large number of individuals at Calspan. The authors are particularly grateful to: Mr. N. L. Infanti and Mr. R. E. Smith who were safety pilots and Mr. M. L. Parrag and Mr. C. J. Berthe, Jr. who served as evaluation pilots. The efforts of Mr. T. J. Gavin and Mr. T. J. Franclemont in maintaining the electronic systems are greatly appreciated as are the efforts of those responsible for mechanical maintenance, Mr. E. G. Frantz, Crew Chief, Mr. W. A. Wilcox, Installation Section Head, Mr. D. E. Dobmeier, Inspection and Mr. J. W. Hooper, Jr. and Mr. M. A. Sears, mechanics, and Mr. J. W. Babala and Mr. M. J. Bergum, the MLD crew. Finally, special thanks are given to Mr. J. R. Lyons for his efforts in data reduction and Ms. J. Cornell and Ms. C. L. Turpin for their contributions to the preparation of this report.

ABSTRACT

This fifth simulation experiment, using the U.S. Navy X-22A variable stability V/STOL aircraft, was undertaken to generate data for the development of flying qualities and advanced flight control system design criteria for the visual shipboard landing task. Since duplication of a ship landing pad and superstructure was impractical, the X-22A Head-Up-Display was employed to present to the pilot position information relative to a simulated ship landing pad. To evoke pilot control and stabilization activity similar to that in the actual shipboard environment, both discrete three-dimensional position tracking and landings to a simulated pad approximately fifty feet above the actual ground were employed as piloting tasks. A microwave landing system with precision ranging capability served as the guidance sensor for both the translational rate flight control system mechanizations and for the HUD tracking information. A total of 111 evaluations were performed of various horizontal and vertical translational rate flight control system dynamics. The primary results of the program defined regions of satisfactory and acceptable flying qualities as functions of velocity command gain and the time constant of velocity response. The limits on command gain and time constant for satisfactory flying qualities indicated by this experiment are considerably smaller than those determined in ground simulator experiments.

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GLOSSARY OF SYMBOLS AND ABBREVIATIONS

Symbol	
F	equations-of-motion characteristic matrix (1/sec)
F_{AS}	roll stick force (lb)
F_{ES}	pitch stick force (lb)
F_g	gust derivative matrix
g	acceleration due to gravity (32.2 ft/sec^2)
G	equations-of-motion control matrix
K_a	roll control command gain (in./in.)
K_c	throttle control command gain (deg/in.)
K_e	pitch control command gain (in./in.)
K_p	roll rate feedback gain (in./rad/sec)
K_q	pitch rate feedback gain (in./rad/sec)
K_r	yaw rate feedback gain (in./rad/sec)
K_R	yaw control command gain (in./in.)
$K_{\dot{x}}$	longitudinal velocity feedback gain (in./ft/sec)
$K_{\dot{x}_c}$	longitudinal velocity command gain (ft/sec/in.)
$K_{\dot{y}}$	lateral velocity feedback gain (in./ft/sec)
$K_{\dot{y}_c}$	lateral velocity command gain (ft/sec/in.)
K_z	altitude feedback gain (deg/ft)
$K_{\dot{z}}$	altitude rate feedback gain (deg/ft/sec)
K_θ	pitch attitude feedback gain (in./rad)
K_ϕ	bank angle feedback gain (in./rad)
$L'_{(\ )}$	dimensional rolling moment derivative

$$= \frac{1}{I_x}\left(1 - I_{xz}^2/I_x I_z\right)^{-1}\left[\frac{\partial L}{\partial (\ )} + \frac{I_{xz}}{I_z}\ \frac{\partial N}{\partial (\ )}\right]\left(\frac{\text{rad/sec}^2}{(\ )}\right)$$

$M_{(\ )}$	dimensional pitching moment derivative $= \frac{1}{I_y} \frac{\partial M}{\partial (\ )} \left(\frac{\text{rad/sec}^2}{(\ )}\right)$
$N'_{(\ )}$	dimensional yawing moment derivative $= \frac{1}{I_z} (1 - I_{xz}/I_x I_z)^{-1} \left[\frac{\partial N}{\partial (\ )} + \frac{I_{xz}}{I_x} \frac{\partial L}{\partial (\ )}\right] \left(\frac{\text{rad/sec}^2}{(\ )}\right)$
p	body axis roll rate (deg/sec, rad/sec)
q	body axis pitch rate (deg/sec, rad/sec)
r	body axis yaw rate (deg/sec, rad/sec)
s	Laplace operator $\sigma \pm j\omega$
t	time (sec)
$T_{\dot{x}}$	first order equivalent longitudinal velocity time constant (sec)
$T_{\dot{y}}$	first order equivalent lateral velocity time constant (sec)
u	velocity along body X-axis (ft/sec)
u_g	longitudinal gust velocity (ft/sec)
v	velocity along body Y-axis (ft/sec)
v_g	lateral gust velocity (ft/sec)
w	velocity along body Z-axis (ft/sec)
w_g	vertical gust velocity (ft/sec)
X, Y, Z	generalized position coordinates (ft)
$X_{(\ )}$, $Y_{(\ )}$, $Z_{(\ )}$	dimensional longitudinal, lateral, and vertical force derivatives $= \frac{1}{M} \frac{\partial x, y \text{ or } z}{\partial (\ )} \left(\frac{\text{ft/sec}^2}{(\ )}\right)$

$\delta_{(\ )}$	evaluation pilot's controller position
	AS - lateral stick (in.), positive right
	RP - rudder pedal (in.), positive right
	ES - longitudinal stick (in.), positive aft
	T - throttle lever (in.), positive forward
$\delta_{(\ )}$	control surface position in units of safety pilot's controller position
	a - lateral stick (in.), positive right
	r - rudder pedal (in.), positive right
	e - longitudinal stick (in.) positive aft
	c - collective stick (deg), positive up
ζ	damping ratio
θ	pitch attitude (deg, rad)
λ	X-22A duct angle measured from horizontal (deg)
λ	first order eigenvalue (1/sec)
λ_c	collective axis forward loop integral gain
λ_r	yaw axis forward loop integral gain
μ	mean value
σ	standard deviation real portion of Laplace operation
τ	generalized time delay (sec)
ϕ	roll angle (deg, rad)
ψ	heading angle (deg)
ω	generalized angular frequency imaginary portion of Laplace operator (rad/sec)
ω	undamped natural frequency (rad/sec)
$(\dot{\ })$	time rate of change of ( ), ( )/sec
$(\hat{\ })$	estimate of ( ), units of ( )

GLOSSARY OF SYMBOLS AND ABBREVIATIONS (Cont.)

$(\ )^T$	transpose of matrix ( )
$(\ )_e$	earth axis
$(\ )_h$	heading axis
$(\ )_{init}$	initial value of ( ), units of ( )
$(\ )_{ss}$	steady state value of ( ), units of ( )

<u>Abbreviation</u>

CRT	cathode ray tube
CTOL	conventional take-off and landing
DME	distance measuring equipment
F-( )	flight number ( )
ft	feet
HUD	head-up-display
in.	inches
LORAS	Linear Omnidirectional Resolving Airspeed System
MLS	Microwave Landing System
PDU	Programmable Display Unit
PR	Cooper-Harper pilot rating
PRS	Precision Ranging System
rad	radian
sec	second
TRC	Translational Rate Control
V/STOL	vertical/short take-off and landing
VTOL	vertical take-off and landing

Section 1
INTRODUCTION

Next generation Navy VTOL aircraft will be required to operate from small aviation ships under conditions of reduced visibility, higher sea states, and more severe winds compared to today's Navy helicopters. For example, the near term goal of the NAVTOLAND SH-2F demonstrator development program is the performance of landings with zero ceiling, visibility of 700 feet and in environments up to Sea-State 5. One of the factors limiting the operational capability of current VTOL aircraft, including helicopters with pitch and roll attitude command and heading hold flight control systems, is the high pilot workload associated with stabilization of the aircraft in the presence of ship air wake, ambient turbulence and large deck motion. Next generation non-helicopter VTOL's with high disc loading will experience similar difficulties but the pilot workload may be increased by the lower effective thrust-to-weight ratio and moment control power.

Inertial translational rate command (TRC) systems seem to show considerable promise to alleviate many of the stability and control difficulties in the landing flight phase because of their inherent gust-proofing characteristics and their relief of the pilot's inner loop attitude stabilization role. Furthermore, ground-based simulator studies indicate that these benefits can be realized with reduced moment control power compared to less sophisticated augmentation systems such as rate or attitude command (Reference 1). The recent development of small, accurate guidance sensors such as the Microwave Landing System (MLS) with precision ranging capability has made the implementation of such flight control systems practicable in the small ship environment.

This report describes an in-flight simulation program, using the U.S. Navy X-22A variable stability aircraft, whose objective was to provide meaningful data for the development of flying qualities and flight control design criteria for TRC systems in visual shipboard landings. A visual task was selected to focus on flight control system characteristics and to eliminate questions of control/display interaction. Since operational and flight

safety considerations precluded replication of the near ship environment, an equivalent task was devised using the X-22A Head-Up-Display (HUD) to provide position information. Although the experiment emphasized longitudinal and lateral control, vertical augmentation requirements were also examined in simulated landings to ensure that the experimental results were not compromised by inadequate height control characteristics. In addition, the experiment addressed the question of control power requirements for these control implementations both by measurements of control power utilized and by limiting available control to determine the degradation in flying qualities and task performance.

The remainder of this report is organized as follows. Section 2 discusses the purpose and goals of the experiment together with background material relevant to TRC control implementations and the development of the evaluation task and the flight control systems design. The conduct of the experiment is presented in Section 3 while Section 4 discusses the program results and their relationship to other experimental data. Finally, Sections 5 and 6 presents the conclusions and recommendations for further work.

Section 2
DESIGN OF THE EXPERIMENT

2.1 BACKGROUND AND PURPOSE

Depending on vehicle configuration, horizontal translational rate control can be realized either through modulation of X and Y forces or through tilting the thrust vector by rotation of the entire vehicle, that is, attitude-type TRC. Direct force, attitude and blended TRC systems have been implemented in flight vehicles (References 2 and 3) and investigated in ground-based simulators (References 1 and 4 to 6). Unfortunately, most of these programs involved specific control configurations so the data base for criteria development is limited. These data do indicate, however, that with suitable dynamics, attitude-type TRC systems can provide improved flying qualities compared to less sophisticated control implementations in demanding hovering tasks, although the minimum translational time constant achievable appears to be limited by the magnitude of the attitude excursions required. Direct force implementations obviate this difficulty but can produce undesirable side accelerations in the cockpit in response to control inputs. The pilot rating data of Reference 4 indicate a slight preference for attitude-type TRC systems, not because of superior performance but because of their better ride quality characteristics. Possibly, the greatest factor against direct force implementations is that unless these devices are also required for other purposes (i.e., transition or yaw control) their inclusion in an air vehicle will impose penalties of weight, complexity and cost since they will not supplant moment controllers. Direct force TRC control implementations will be included in advanced VTOL's only if the requisite flying qualities cannot be provided by attitude-type TRC systems.

For these reasons, the current experiment was directed to attitude-type TRC control implementations only. Although the X-22A can control X-force directly through collective modulation of the elevons, this capability was not used in this experiment.

In support of the experiment design, an analysis was conducted to determine the anticipated closed-loop characteristics of the X-22A, the influence of inherent characteristics on augmented dynamics and to examine potential TRC control criteria. The results of that analysis are presented in the following subsection.

2.2 CONTROL SYSTEMS DESIGN

2.2.1 Longitudinal/Lateral Translational Rate Control Systems

The objective of the longitudinal and lateral flight control system parameter variations was to generate a data base for the correlation of flying qualities with the vehicle's closed-loop modal characteristics. Of particular interest was the feasibility of developing flying qualities criteria based on reduced order system dynamical models paralleling the CTOL equivalent system models employed in the military flying qualities specification MIL-F-8785C (Reference 7). Accordingly, analyses were performed first to establish the dynamics of the X-22A with translational rate augmentation, to establish gain ranges for command and feedback parameters to facilitate the criteria development and to relate the estimated closed-loop dynamics to previous experimental investigations. In the discussion to follow, the longitudinal axis is used for illustration; the behavior of the augmented lateral axis is similar and is not discussed separately.

The TRC control systems implemented for this experiment are comprised of inner loop attitude stabilization with an outer velocity loop (Figure 1). In structure, the longitudinal and lateral systems are identical. The inertial velocity signals for all axes are derived from complementary filtering of on-board accelerometer and MLS position data resolved into an aircraft heading axis system (Reference 8). Additional workload relief functions such as auto trim (i.e., forward loop integration) were considered but not implemented on the basis that the simulated atmospheric disturbances were zero mean and the task primarily involved maneuvering. Accordingly, velocity trim was accomplished manually through the X-22A parallel trim system.

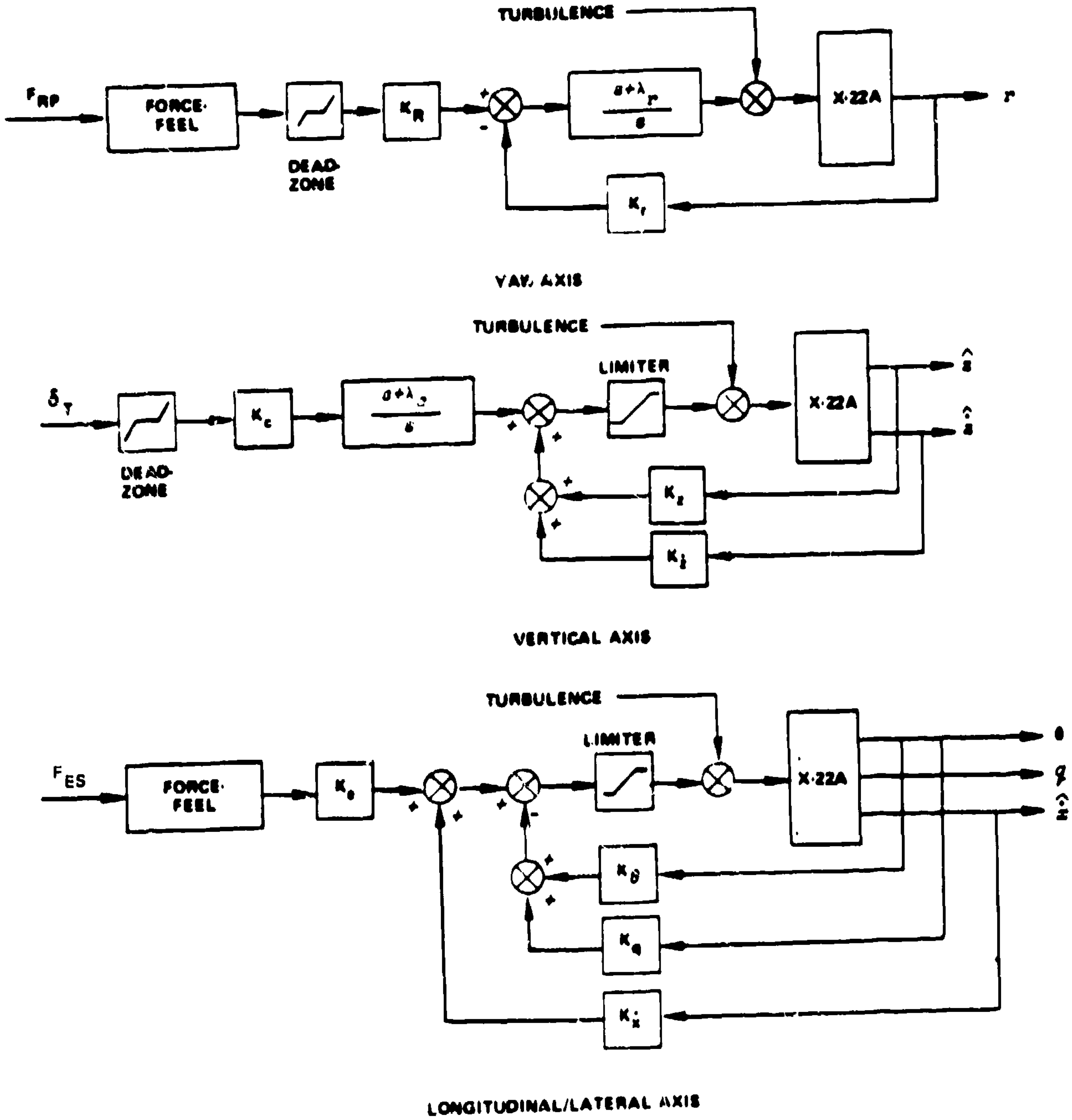


Figure 1 FLIGHT CONTROL SYSTEM BLOCK DIAGRAMS

No attempt was made to modify the stability and control characteristics of the X-22A to match any specific VTOL configuration. Since the disc loading of the X-22A lies between that of helicopters and jet lift VTOL's, its inherent dynamic characteristics (with the possible exception of drag damping) are considered representative for a generalized VTOL flying qualities investigation.

2.2.1.1 TRC Dynamic Characteristics

Identification of the X-22A dynamics from a previous flight program (Reference 8) indicates that in hover and low speed, the height dynamics are reasonably well decoupled from the pitch and roll translational modes. Accordingly, the translational dynamics are 3rd order and are represented by the following state equation:

$$\begin{bmatrix} \ddot{x} \\ \ddot{\theta} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & 0 & -g \\ M_u & M_q & 0 \\ 0 & 1.0 & 0 \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{\theta} \\ \theta \end{bmatrix} + \begin{bmatrix} 0 \\ M_{\delta_e} \\ 0 \end{bmatrix} \begin{bmatrix} \delta_e \end{bmatrix} \tag{1}$$

This equation assumes still air and small angles so that airspeed (u) and inertial velocity $(\dot{x})$ can be used interchangeably. Since the X-22A derives pitch and roll moment control from fore-aft and side-to-side differential thrust, the force derivatives X_{δ_e} and Y_{δ_a} are negligibly small. Thus, all horizontal translational forces must be generated through attitude changes. The flying qualities exhibited by these TRC control systems will be influenced primarily by the nature of the response to control commands and the response to external disturbances. For the augmentation system of Figure 1, the response to control is governed by the three eigenvalues of the characteristic equation. Figure 2 illustrates typical loci for the characteristic roots for closures of the attitude and velocity loops, respectively. In terms of the stability and control parameters, the transfer functions of velocity and attitude response are given by:

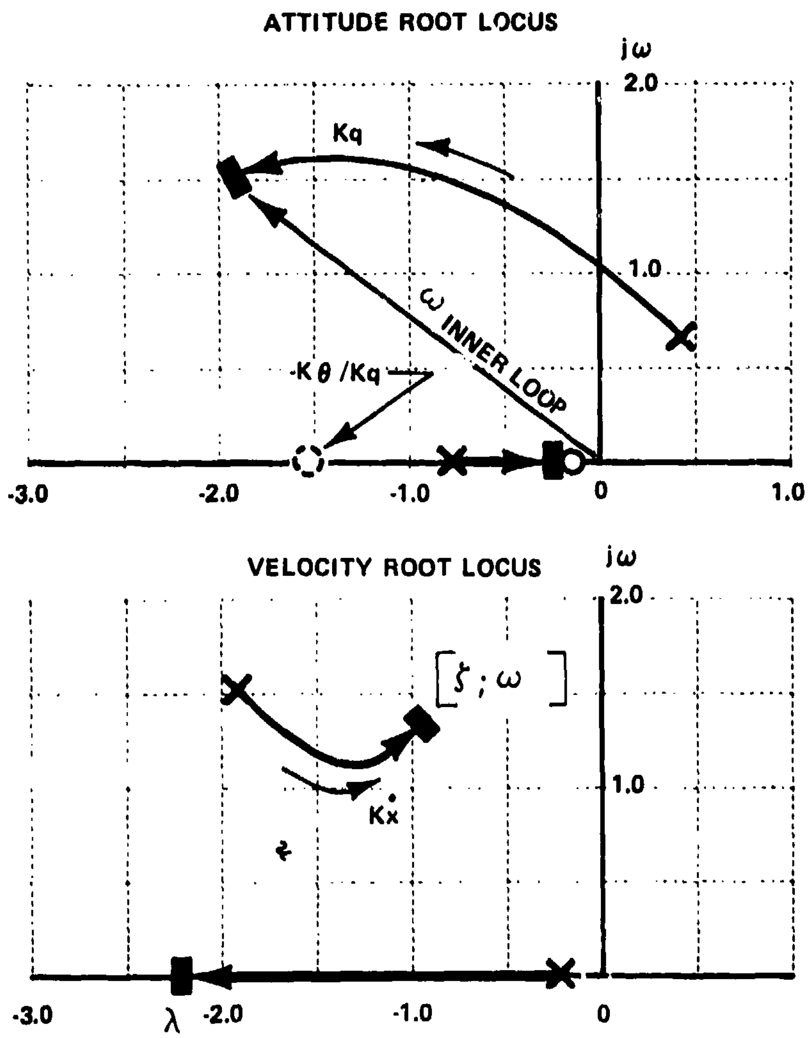


Figure 2 ROOT LOCI FOR ATTITUDE AND VELOCITY CLOSURES

$$\frac{\dot{x}}{\delta_{ES}} = \frac{-K_e M_{\delta_e} g}{(s-X_u)(s^2+(K_q M_{\delta_e} - M_q)s + K_\theta M_{\delta_e}) + g(M_u + K_{\dot{x}} M_{\delta_e})}$$

$$= \frac{-K_{\dot{x}_c}}{(1+s/\lambda)(1+(2\zeta/\omega_n)s+(s/\omega_n)^2)} \tag{2}$$

$$\frac{\theta}{\delta_{ES}} = \frac{s-x_u}{g} \; \frac{K_{\dot{x}_c}}{(1+s/\lambda)(1+(2\zeta/\omega_n)s+(s/\omega_n)^2)}$$

The modal parameters (λ, ζ, ω_n) are uniquely determined by the feedback gains $K_{\dot{x}}$, K_q and K_θ. The ground simulator experiments described in References 1 and 5 indicate a pilot preference for well-damped velocity responses (i.e., little or no overshoot) which implies a lower limit for the damping ratio. In fact, the majority of evaluations in the Reference 1 experiment were conducted with a binomial form characteristic equation, that is $\lambda = \omega_n$ and $\zeta = 1.0$. Configurations with a Butterworth form characteristic equation ($\lambda = \omega_n$, $\zeta = 0.5$) were objectionable because of the low damping and the tendency for control responses to overshoot.

With sufficiently high system damping, Reference 5 notes that the velocity response approximates that of a first order system and proposes, as a possible criterion, the equivalent path mode time constant, $T_{\dot{x}}$ (i.e., the time to 63 percent of steady response). The appeal of such a simple flying qualities criterion is obvious since it reduces the number of modal parameters required for correlation from three to one and the system can be described simply in terms of the steady state velocity gain, $K_{\dot{x}_c}$ (ft/sec/inch), and the equivalent path mode time constant, $T_{\dot{x}}$.

It is questionable, however, whether a first order path mode criterion adequately addresses all factors of significance to flying qualities. First, even with the damping ratio fixed, λ and ω_n can be traded off to produce an infinity of systems with equal path mode time constant. Two such systems are compared in Figure 3. With ω_n large compared to λ, the initial velocity response is faster but the final capture of commanded velocity is more sluggish than with λ greater than ω_n.

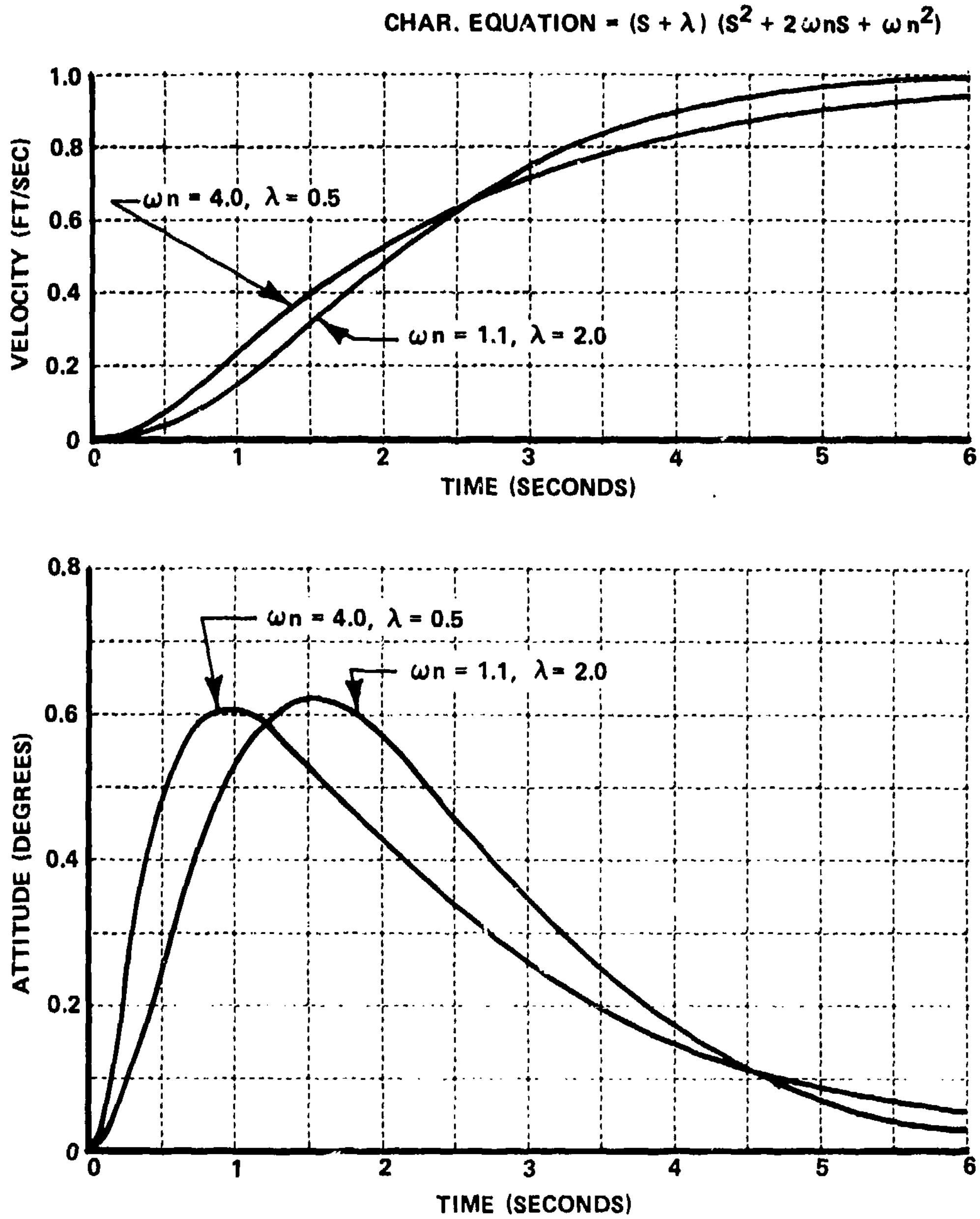


Figure 3 COMPARISON OF TWO TRC SYSTEMS WITH 2.5 SECOND FIRST ORDER PATH MODE TIME CONSTANTS

Furthermore, for $\omega_n > \lambda$, the faster initial velocity response is achieved at the expense of higher initial pitch rates and accelerations. Since Reference 5 cites attitude abruptness as the factor limiting the minimum achievable path mode time constant, these data suggest that the magnitude of λ relative to ω_n must also be considered in addition to the magnitude of the equivalent path mode time constant.

In addition to this ambiguity in characterizing response to control, a first order path mode approximation also does not adequately reflect differences in gust or turbulence sensitivity due to the relative magnitude of inherent speed stability and augmented velocity stability. As can be seen by the lateral coefficients of the characteristic equation (equation 2), the dynamics of velocity response reflect the sum of M_u and $M_{\dot{x}} = K_{\dot{x}} M_{\delta_e}$. That is, in still air, speed and velocity stability are interchangeable from the standpoint of response to control. However, in turbulent or gusty air, aerodynamic speed stability tends to couple the vehicle to the airmass while inertial velocity stability suppresses this coupling. To illustrate, Figure 4 presents frequency responses of $\dot{x}$ to a longitudinal gust for two hypothetical augmented configurations. Each configuration has identical response to control but for one system the speed stability term is entirely aerodynamic while,for the second system, $M_u = 0$ and all velocity stability is derived from inertial feedback. With no inertial velocity feedback, the aircraft is effectively coupled one to one with the airmass up to a frequency of the order of 1.0 rad/sec. In the second case, the substitution of inertial velocity stability for speed stability produces a 75 percent reduction in inertial velocity response. Clearly, the gust responsiveness is highly dependent on the relative magnitudes of inertial and aerodynamic speed stability. Since the path mode time constant reflects only the sum of aerodyanmic and inertial speed stability, this parameter provides no accountability for turbulence sensitivity.

Based on these considerations, the TRC systems for this experiment were designed first, to establish the sensitivity of pilot rating and task performance to velocity gain and path mode dynamics and second, to explore the effect of variations in the relative magnitudes of aerodynamic and inertial speed stability. These objectives were addressed as follows.

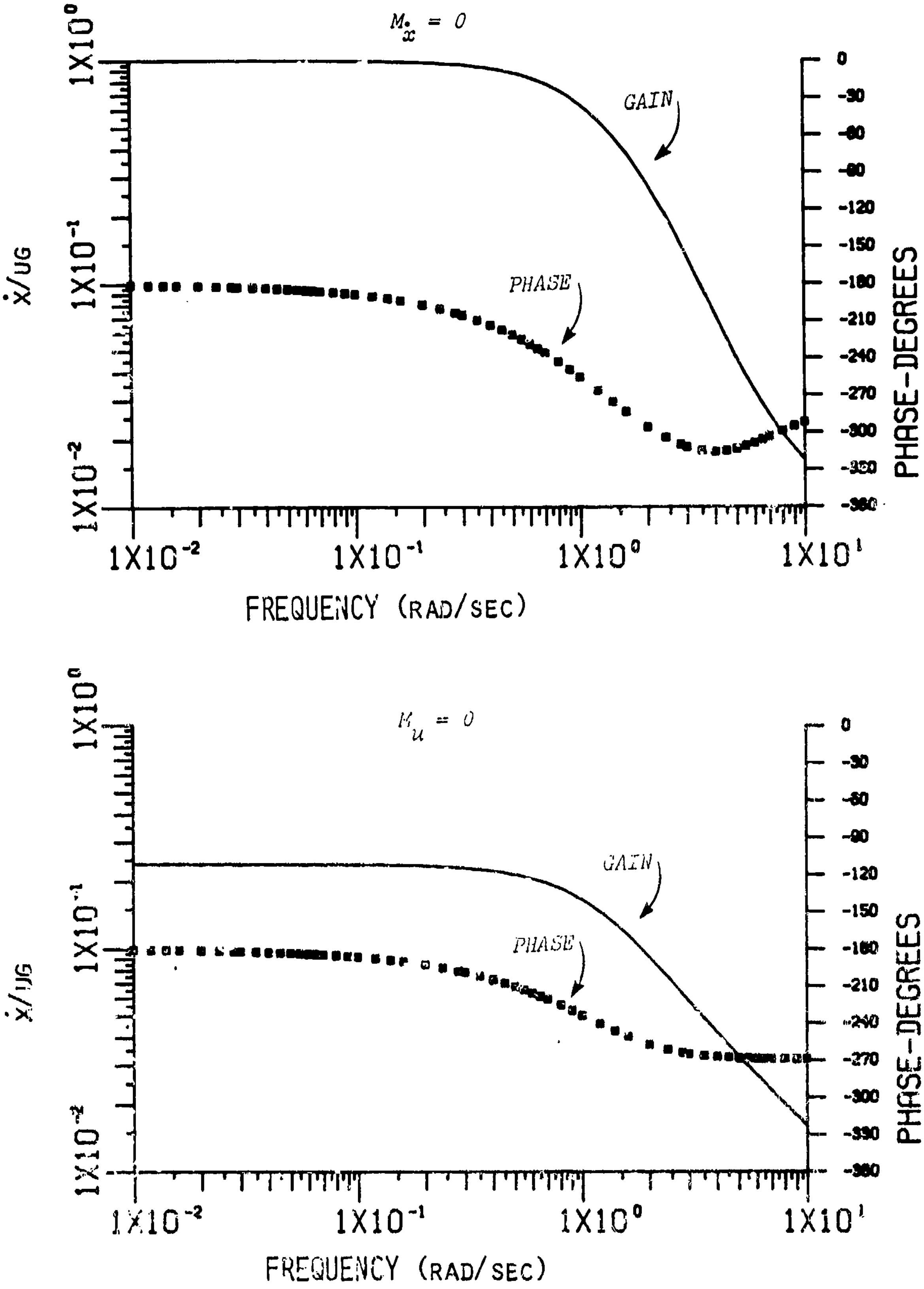


Figure 4. COMPARISON OF LONGITUDINAL VELOCITY RESPONSE TO LONGITUDINAL TURBULENCE WITH $M_u = 0$ AND $M_{\dot{x}} = 0$

A baseline matrix comprised of variations in steady state velocity sensitivity and path mode time constant was established based on constant inner loop attitude dynamics with damping ratio equal to 0.8 and natural frequency of 2.5 radians/second. This damping ratio was selected to provide well-damped velocity responses for all path mode time constants since, as indicated in Figure 2, the damping ratio of the complex characteristic roots tends to be reduced at high velocity feedback gains. Evaluations of configurations in this matrix were intended to establish nominal requirements for gain and velocity response dynamics. Secondary matrices based on inner loop attitude systems with natural frequencies of 2.0 and 3.0 radians/second were also designed to address the tradeoff of aerodynamic and inertial velocity stability.

Design parameters and response characteristics for these systems are illustrated in Figure 5. Figure 5a plots the velocity feedback gain required as a function of the equivalent path mode time constant for each of the inner loop natural frequencies. Because the higher frequency inner loop configurations require higher velocity feedback gains to realize a given path mode time constant, these systems will exhibit superior turbulence and gust suppression. A measure of gust immunity is the ratio of inertial to aerodynamic speed stability. This parameter is plotted in Figure 5b to illustrate the relative characteristics.

Unfortunately, the superior gust rejection of the high frequency inner loop TRC systems is achieved at the expense of increased attitude abruptness. At any given path mode time constant, these configurations exhibit response to control similar to those illustrated in Figure 3 ($\lambda < \omega_n$). The relative attitude abruptness, as indicated by the normalized initial pitch acceleration, $\ddot{\theta}_{init}/\dot{x}_{ss}$ is plotted in Figure 5c. At any path mode time constant, TRC systems with inner loop dynamics of 3.0 radians/second exhibit approximately twice the abruptness of 2.0 radians/second systems.

2.2.2 Yaw Axis Control System

Because of the potentially large number of configuration variables, certain measures were taken to reduce the size of the experiment matrix. First,

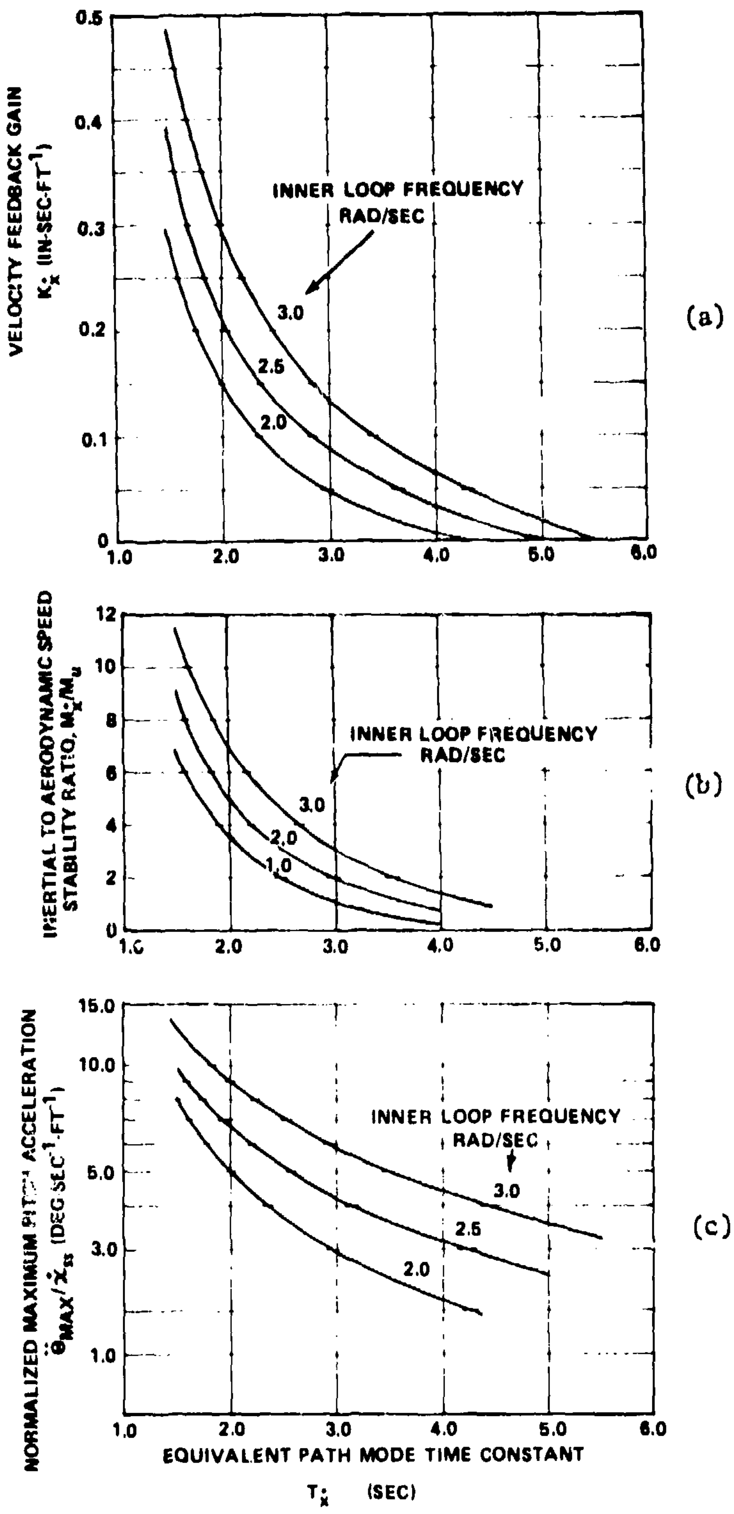


Figure 5 LONGITUDINAL TRC DESIGN AND RESPONSE PARAMETERS

to focus on the characteristics of the translational dynamics, the yaw axis augmentation was held fixed for the experiment and was designed to provide satisfactory, and hence, unobtrusive flying qualities. The achievement of this objective was verified in preliminary practice evaluations. The system illustrated in Figure 1 provides yaw rate responses to pedal commands with psuedo heading hold through the action of the forward loop integrator. The nominal heading dynamics were second order with a natural frequency of 2.0 rad/sec, a damping ratio of 1.0 and a command gain of 8.0 deg/sec per inch of pedal.

2.2.3 Vertical Axis Control System

The X-22A exhibits the inherent low vertical damping typical of intermediate disc loading VTOL's. Thus, height control augmentation was considered essential for the evaluation task described previously. The system, depicted in Figure 1 can operate in two modes. In the first, inertial vertical velocity and altitude feedback to the blade collective pitch were employed to produce an altitude stabilized configuration. Vertical rate responses to throttle commands were achieved by means of an integral proportional network in the throttle command path. An electrical command dead zone centered on the throttle detent position assured zero vertical rate with the throttle in the detent (altitude hold). In the second mode, the altitude feedback gain and the command integrator gain were set to zero thus providing rate responses to throttle commands but with no altitude hold capability.

Although there exists a substantial body of data relating to augmented height dynamics, the applicability of most of these data to the current program was considered questionable because of uncertainties in the tasks employed and because much of the experimental effort was concerned with augmentation of aerodynamic vertical damping. However, from a control standpoint, the data indicated a pilot preference for some minimum level of vertical damping of the order of 0.5 to 1.0 sec^{-1}. Similar requirements are evidenced in the results of an inflight investigation of VTOL instrument approach to hover (Reference 9) using inertial vertical velocity command augmentation. This experiment indicated that the best flying qualities were achieved with a vertical response time

constant of 2.0 seconds and a control sensitivity of 0.2 g's/inch.

Because of pilot preference for first order-like velocity responses to control commands, a quasi model-following approach was used with the altitude stabilized control systems. For each vertical augmentation configuration, the altitude and altitude rate feedback gains were selected to realize a critically damped second order characteristic equation. The integral proportional prefilter gains were then selected to cancel one of the characteristic roots. The remaining real root then determined the time constant of the vertical velocity response. This design approach was taken to allow direct comparison of vertical rate command and altitude hold configurations with identical control response characteristics.

2.3 TASK DEVELOPMENT

It was recognized at the outset of the program that the validity of the experimental results would be directly related to the fidelity of the visual and motion cues and the degree to which these stimuli evoke pilot control and stabilization activities similar to the real world. For in-flight simulators, fidelity of motion cues is generally no problem. However, for this program a particular challenge was the provision of adequate visual cues equivalent to the near-ship environment.

For the purpose of criteria development, it was intended to simulate dynamic configurations with flying qualities ranging from satisfactory to uncontrollable. Therefore a minimum hover height of 50 feet was established to provide a margin for recovery from dangerous flight conditions. For this reason, and because of the difficulty of simulating ship landing pad motion, duplication of a pad and ship superstructure was judged impractical. Maneuvering over ground markings was also considered but was rejected because of the difficulty in ensuring that the pilot would approach each evaluation with a constant and consistent set of performance standards. Furthermore, at the minimum hover altitude of 50 feet, the resolution of horizontal position cues is poor and only limited vertical maneuvering would be possible. Although this task was rejected as a primary task, it was decided to perform a limited number of evaluations in ground referenced maneuvers to allow comparisons with

the task finally adopted and, in effect, to calibrate the experiment with respect to a "classical" hover flying qualities evaluation procedure.

2.3.1 Use of Head-Up-Display

For the reasons cited above, the approach taken was to use a combination of the X-22A head-up-display (HUD) for position information and the real world for visual orientation cues. The display format, devised after preliminary ground and in-flight testing by Calspan and Navy pilots, is presented in Figure 6. The information presentation is symbolic since the field of view of the HUD effectively precludes a pictorial presentation of the landing pad and the ship superstructure. The salient features of the display are the fixed aircraft symbol and altitude ladder with rung separation scaled to 10 feet. Longitudinal and lateral displacement from the landing pad (square symbol) are presented in planview in a heading-up axis system. Referring to Figure 6, closure with the pad would require forward and right stick. Height above the landing pad is depicted by the separation of the double dumbbell and the airplane symbol, in effect, an elevation view of the vertical situation. As in the X-Y situation presentation, the control sense is fly to, that is, the dumbbell symbol is the landing pad. Orientation information, pitch and roll attitude and heading, was not displayed on the HUD since these cues were derived from the outside world.

2.3.2 Discrete Tracking Task

Initial efforts to devise an evaluation task were directed to achieving as much realism as possible. To this end, a prerecorded ship motion signal representative of Sea State 5 conditions was prepared using a sum-of-sine-waves model (Reference 10). Preliminary ground simulator and in-flight evaluations confirmed the experience of LAMPS pilots in small ship operations, that is, tracking deck motion in Sea State 5 is impossible. As in the real flight environment, the technique for landing was to establish a stationkeeping position relative to the pilot's estimate of the mean deck position and to close on the landing pad in anticipation of or following the detection of a lull in the ship motion. Although this technique is realistic procedurally, the pilot was engaged in a tight control task only during the relative brief period of closure with the pad. In addition, the pilots commented that it was difficult, when maneuvering,

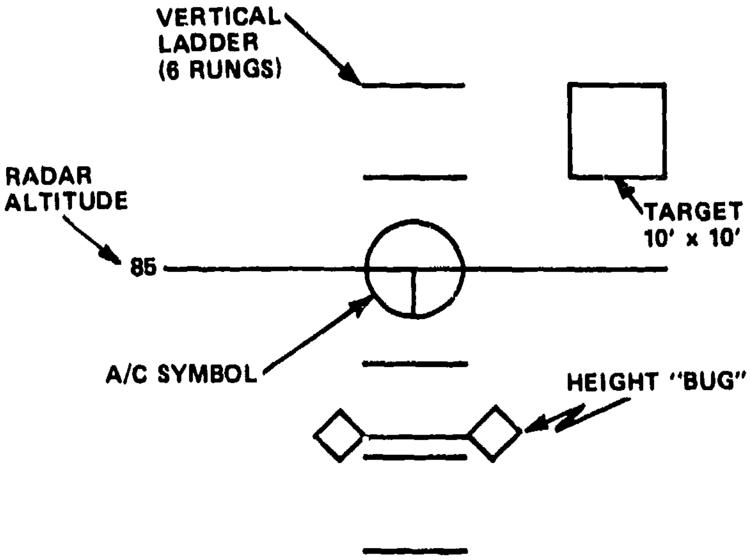


Figure 6. HEAD-UP-DISPLAY SYMBOLOGY FOR HOVERING TASK

to distinguish control-induced motion of the aircraft from deck motion. This confusion, in part, is a result of displaying only the error signal of aircraft displacement from the landing pad. Consequently, it was concluded that this task would be both wasteful of valuable flight time and unrealistically difficult from the standpoint of relative motion perception.

A pursuit as opposed to compensatory display showing aircraft and landing pad displacement relative to the mean deck position may have alleviated these difficulties but would have violated the ground rule of simulation of visual contact ship landings. That is, in the real world the mean deck position is a computed rather than a physically observable position and, furthermore, display of this parameter presupposes the existence of deck motion as well as aircraft motion sensors. As a result, the ship-motion model was abandoned and in its place was substituted a tape-recorded series of random appearing, discrete changes in landing pad position. Pad position changed once every 20 to 30 seconds in increments of 20-25 feet and in combinations of X-Y and Y-Z directions. The task was mechanized so that the mean pad position was fixed in inertial space at the position of system engagement (altitude of 75 to 100 feet).

This discrete tracking task offered several advantages over continuous ship motion. First, since the pad changed position in a stepwise fashion, the pilot had no trouble distinguishing pad motion from aircraft motion. Second, utilization of flight time was maximized since the pilot was continuously engaged in a tight control task. Finally, the task was repeatable and paced in that the pilot had only a finite time in which to position himself over the pad. Consequently, it was felt that the pilot was more likely to apply a consistent performance standard to each evaluation.

A survey of helicopter small ship landing procedures and interviews with LAMPS pilots indicated that the landing task in high sea states was comprised of a sequence of maneuvers as follows:

1. Horizontal (X-Y) maneuvering - moving into position over the landing pad at the termination of the approach.

2. Stationkeeping over the mean pad position to await a lull in deck motion.

3. Descending to the pad - establishing the desired sink rate and descending to deck while maintaining X-Y position - maneuvering in all directions may be required to avoid superstructure or premature deck contact.

A sequence of maneuvers for the X-22A evaluation task was devised with the intent of exercising pilot control over the same degrees of freedom as in a real landing maneuver. This sequence was comprised of:

1. Discrete tracking in X-Y.
2. Discrete tracking in Y-Z.
3. Execution of a vertical landing to the pad, from approximately 20 feet above the pad.

The two tracking sequences were intended to expose the controllability of each configuration in two-axis maneuvers while holding a reference position in the remaining axis. The X-Y maneuvering sequence parallels the real-life horizontal maneuvering required in positioning the aircraft over the landing pad. Although Y-Z maneuvering would not be a customary element of a real shipboard landing, such coordinated maneuvering may be required to avoid deck contact during unexpected heaving or rolling. Finally, the vertical landing sequence focusses on the vertical dynamics together with the precision hover characteristics in X-Y. Although the maneuvering commands take place in, at most, two axes simultaneously, precise control in three dimensions is required.

2.4 TURBULENCE SIMULATION

Random disturbances to the aircraft during evaluation were provided by simulation of random-ship-airwake turbulence using a mathematical model described in Reference 10. However, only the zero-mean random component of this airwake model was simulated. The model was representative of conditions at 15 feet altitude above the landing pad with the aircraft pointed into the

wind which was coming from 30 degrees to port of the ship's heading. The root-mean-square-wind velocity was 8.9 ft/sec in all three orthogonal directions corresponding to a wind-over-deck of 25 knots. The control surfaces of the X-22A were moved in such a way that the resulting vertical, pitching, rolling, yawing and vertical motion of the X-22A equalled the motion it would experience in such a wind environment. The control inputs were calculated using the relation:

$$u = G^{-1} F_g x_g$$

with

$$u = [\delta_e \ \delta_c \ \delta_a \ \delta_r]^T$$

$$x_g = [u_g \ w_g \ v_g]^T$$

$$G = \begin{bmatrix} Z_{\delta_e} & Z_{\delta_c} & 0 & 0 \\ M_{\delta_e} & M_{\delta_c} & 0 & 0 \\ 0 & 0 & N_{\delta_a} & N_{\delta_r} \\ 0 & 0 & L_{\delta_a} & N_{\delta_r} \end{bmatrix}$$

$$F_g = \begin{bmatrix} Z_u & Z_w & 0 \\ M_u & M_w & 0 \\ 0 & 0 & N_v \\ 0 & 0 & L_v \end{bmatrix}$$

2.5 FORCE FEEL SYSTEM CHARACTERISTICS

For all translational rate flight control systems, the control gearings were selected to provide equal steady state velocity response per unit of stick displacement in the longitudinal and lateral axes. Equal response gains were to provide a one-to-one correspondence between the direction of stick displacement and the direction of the resulting velocity vector (i.e., the stick is pointed in the desired direction of flight).

For ergonomic reasons, lower stick force gradients and breakout forces were selected for the lateral axis compared to the longitudinal axis. Table 1 summarizes the force feel system static characteristics.

TABLE 1

FORCE FEEL SYSTEM STATIC CHARACTERISTICS

AXIS	GRADIENT, LB/IN	BREAKOUT FORCE, LB	DEAD ZONE, IN
Pitch	2.5	1.5	---
Roll	2.0	1.0	---
Yaw	20.0	8.0	±0.10

The pedal breakout forces and gradients are somewhat high for hover low speed flight, but were chosen to ensure that pedals returned to the electrical dead zone when pedal force was relaxed. Because of the forward loop integrator in the directional augmentation system, positive pedal centering is required to prevent yaw drift. These force characteristics were satisfactory for the hover task since yaw maneuvering was not required and the heading hold was tight enough to prevent large yaw disturbances.

The throttle control provided adjustable friction only together with an electrical dead zone to prevent altitude drift with the throttle in the zero rate command position. Tactile sense of this position dead-zone was provided for the pilot by means of a notch in the throttle quadrant and a spring-loaded ball in the base of the throttle handle. The dead zone corresponded to ±.05 inches of throttle travel.

The bandwidth and damping of pitch and roll force feel systems ($\omega_n \simeq 12$ rad/sec, $\zeta \simeq 0.6$) were sufficiently high that flying qualities characteristics were not degraded.

Section 3
CONDUCT OF THE EXPERIMENT

3.1 SYNOPSIS OF SECTION

The purpose of this section is to outline the procedures that were used in conducting this flight experiment. The following subsections outline the equipment used, simulation situation, evaluation procedure, and the types of data obtained in the experiment.

3.2 EQUIPMENT

3.2.1 X-22A Variable Stability V/STOL Aircraft

The United States Navy X-22A V/STOL variable stability aircraft was used as the in-flight simulator for this experiment (Figure 7). Briefly, the X-22A is a four-ducted-propeller V/STOL aircraft with the capability of full transition between hover and forward flight. The four ducts are interconnected and can be rotated to change the duct angle and therefore the direction of the thrust vector to achieve the desired operating flight condition defined by a particular speed and duct angle combination. The thrust magnitude is determined by a collective pitch lever, very similar to a helicopter. Normal aircraft-type pitch, roll and yaw controls in the cockpit provide the desired control moments by differentially positioning the appropriate controls in each duct (propeller pitch and/or elevon deflection). A mechanical mixer directs and proportions the pilot's commands to the appropriate propellers and elevons as a function of the duct angle.

The X-22A incorporates a Calspan-designed four-axis (pitch, roll, yaw, thrust) response-feedback variable stability system (VSS) plus a 96-amplifier analog computer designed and fabricated by Calspan. In this experiment the VSS provided the feel system characteristics for the evaluation pilot while the structure of the simulated control system was implemented on the analog computer; the analog computer also provided the landing pad

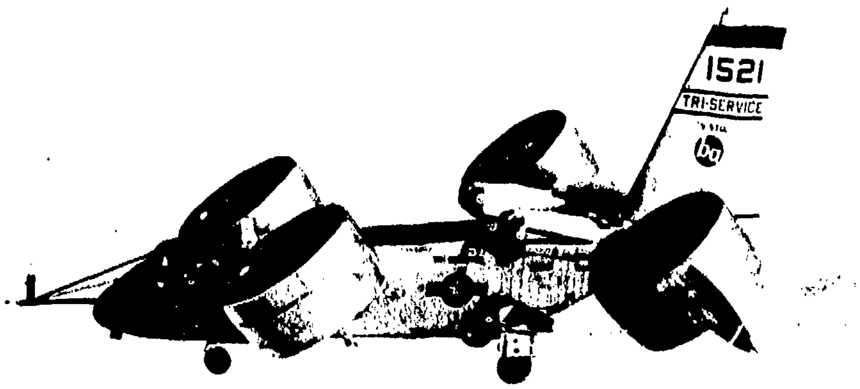


Figure 7. X-22A VARIABLE STABILITY V/STOL AIRCRAFT

relative position information for the Head-Up-Display (HUD). The evaluation pilot's control inputs (from the left hand seat in this aircraft) in the form of electrical signals, are summed through the analog computer and VSS with the appropriate signals proportional to the aircraft motions to operate the right hand flight controls through electrohydraulic servos. The system operator, who also serves as the safety pilot, occupies the right hand seat, and operates the aircraft through the primary flight control system when the VSS is disengaged. All of the VSS input and response-feedback gain controls are located beside the safety pilot; fourteen potentiometers for the analog computer are located next to the evaluation pilot.

Control feel to the evaluation pilot's stick and rudder pedals is provided by electrically controlled hydraulic feel servos which provide opposing forces proportional to the stick or rudder deflections; in effect, a simple linear spring feel system. Note that the evaluation pilot can not feel the X-22A control motions produced by the variable stability system. Since this experiment was directed to VTOL,as opposed to helicopter flying qualities, the normal collective stick controller for the evaluation pilot was replaced by a fore-aft throttle-type controller.

A variable Head-Up Display capability was provided for this experiment by a Smiths Industries Pilot Display Unit (PDU) in conjunction with a Smiths Industries Graphics Generator and an airborne Data General NOVA 3/12 digital computer. The PDU, which includes CRT, optics, and combining glass, was mounted on a retractable mechanism to assure correct eye-to-glass distance and yet permit clearing the PDU from the ejection envelope. The graphics generator and digital computer provide the capability to generate display information formats for either head-up or head-down presentation. Complete programming flexibility permits an essentially unlimited range of calligraphic symbology and alphanumerics for the replication of existing electonic formats or the design of new ones. The computer is controlled from a remote miniature terminal in the cockpit so that any desired format can be selected in flight. This capability is very important for in-flight research experiments as different display presentation may be evaluated during flight without landing

and reprogramming the symbol generator. The evaluation pilot's instrument panel incorporating the HUD is shown in Figure 8.

A more complete description of the X-22A systems is contained in Reference 11.

3.2.2 Microwave Landing System

For this experiment, position data relative to the selected hover pad was provided by a Microwave Landing System (MLS) developed by the U.S. Army Electronics Command and built by the AIL Division of Cutler-Hammer, Inc. and a Precision Ranging System loaned to Calspan by the Honeywell Corporation. The MLS system uses the scanning beam technique; airborne equipment in the X-22A decodes absolute azimuth, elevation, and range, resolves them into XYZ position data, and blends them with onboard accelerometer data through complementary filters to provide smooth estimates of translational positions and velocities. A summary of the resolution and filter equations is given in Reference 8. A suppression system, required to prevent control transients in the event of MLS signal loss, is described in Appendix III.

3.2.3 Data Acquisition System

Both experimental and flight safety data were telemetered to and monitored by the Digital Data Acquisition and Monitoring System developed expressly for the X-22A by Calspan and housed in a mobile van. Since the complexity of the X-22A makes it impossible for the pilot to monitor all the important flight safety parameters, it is essential to have ground monitoring of the flight safety variables. The flight safety variables were monitored on chart recorders and by a digital mini-computer in the van. In addition, a continuous recording of all telemetered data, including radar position data and the guidance relationships performed in the analog computer, was obtained on the "bit-stream" recorder for later analysis and processing. The details of the Digital Data Acquisition System are covered more fully in Reference 12.

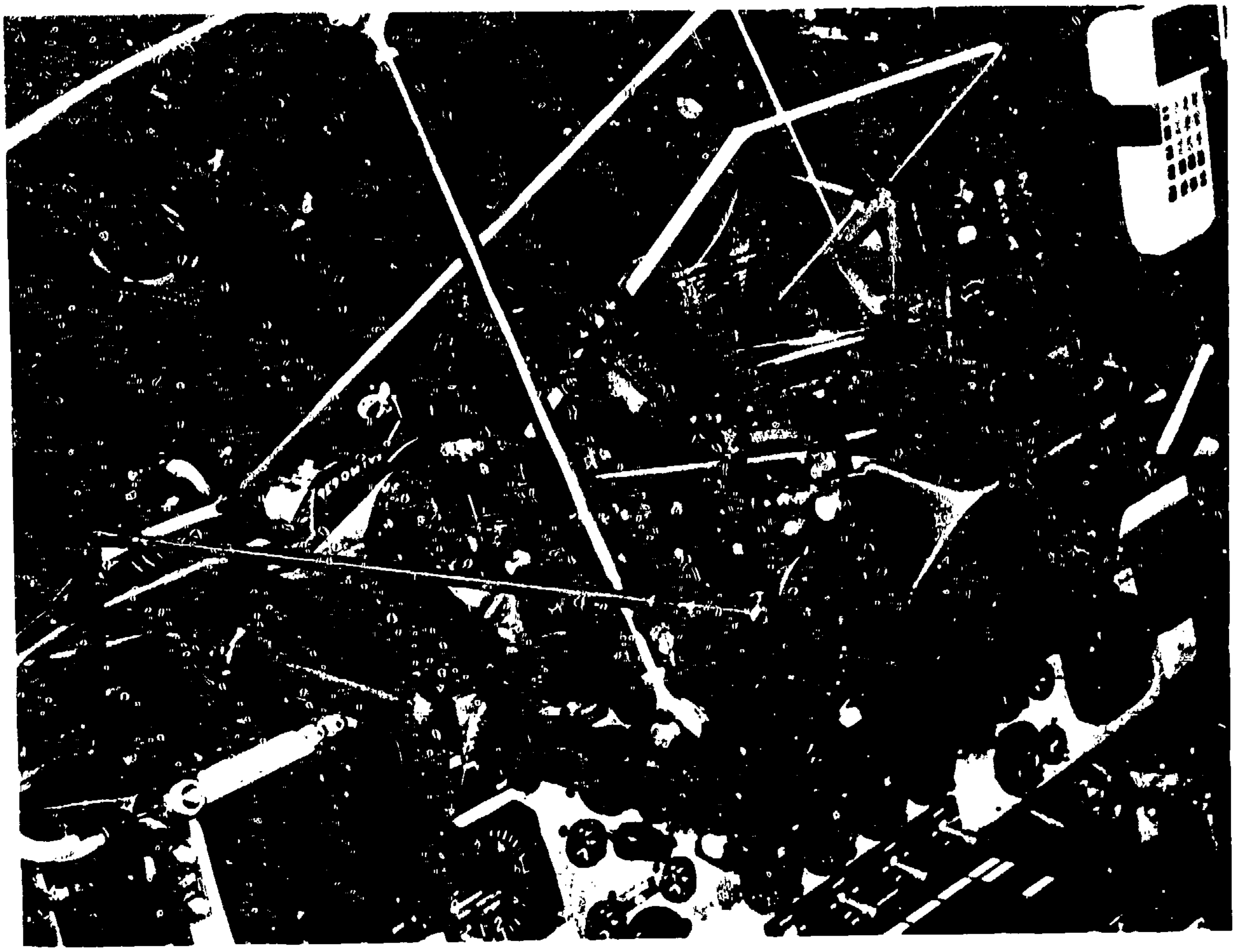


Figure 8. EVALUATION PILOT INSTRUMENT PANEL AND HEAD-UP DISPLAY

3.3 CONFIGURATION SETUP PROCEDURE

Prior to the initiation of the evaluation for each configuration, the characteristics of the control system to be investigated and the display presentation were set up in flight by both pilots before engagement of the variable stability system. The setup functions to be performed by each pilot were listed on a card on each configuration and are summarized below.

Safety Pilot

- Set (check) all variable stability force-feel system gains.
- Select HUD format on remote terminal for digital computer.

Evaluation Pilot

- Set selected MLS heading on differential resolver.
- Select artificial turbulence ON or OFF via two-position switch.
- Select via a two-position switch the X-Y or Y-Z discrete tracking task.
- Set 14 potentiometers from the analog computer to select control system gains and control director gains.

3.4 SIMULATION SITUATION

To obtain valid flying qualities data in the form of pilot ratings and comments, careful attention must be given to defining, for the evaluation pilot, the mission which the aircraft/pilot combination will perform and the conditions in which it will be performed. For the current experiment, the simulated aircraft was defined as an all-weather VTOL of intermediate disc loading performing visual shipboard landings; the aircraft was considered a single-pilot operation but no allowance was made for typical additional duties, e.g., communications. Additional factors such as passenger comfort were not considered by the pilot in making his evaluation.

3.5 EVALUATION TASK

Although the mission generally involves many elements, an evaluation of the suitability of the vehicle for the mission can be accomplished by having the evaluation pilot perform a series of maneuvers representative of those tasks anticipated in the mission. With the general conditions defined as above, the specific tasks to be accomplished for each evaluation were defined as sequences of tracking a simulated moving landing pad,first in X-Y,then in Y-Z followed by a vertical landing to a fixed landing pad. For the tracking task, the landing pad symbol was driven by a prerecorded sequence of step commands of approximately 20 ft amplitude with "rest periods" of 20 to 30 seconds to allow pilot closure and hover over the pad. Random atmospheric disturances were simulated by a tape recorded turbulence signal injected into the pitch, roll, yaw and thrust flight control systems.

3.6 EVALUATION PROCEDURE

The evaluation procedure was as follows. Upon completion of the setup procedures discussed in Section 3.3, the safety pilot engaged the VSS, generally within the MLS beam aligned with the localizer centerline at about 600 to 1000 ft range, and the evaluation pilot then performed the maneuver sequences described above. At the conclusion of the evaluation maneuvers, the VSS was disengaged and the safety pilot took over control of the airplane. In this experiment, selected configurations were evaluated with no synthetic turbulence in ground referenced maneuvers or with control power electrically limited. Following disengagement of the VSS, the evaluation pilot then tape-recorded comments with reference to a comment card, assigned separate Cooper-Harper ratings (Figure 9) for the X-Y-Z maneuvering task and the vertical landing task.

The pilot comment card is given below (Figure 10). It is important to note that the purpose of this card is to aid both the pilot in performing his evaluation and the analyst in determining the major reasons for the rating. The ratings by themselves only constitute half the data, therefore, and the

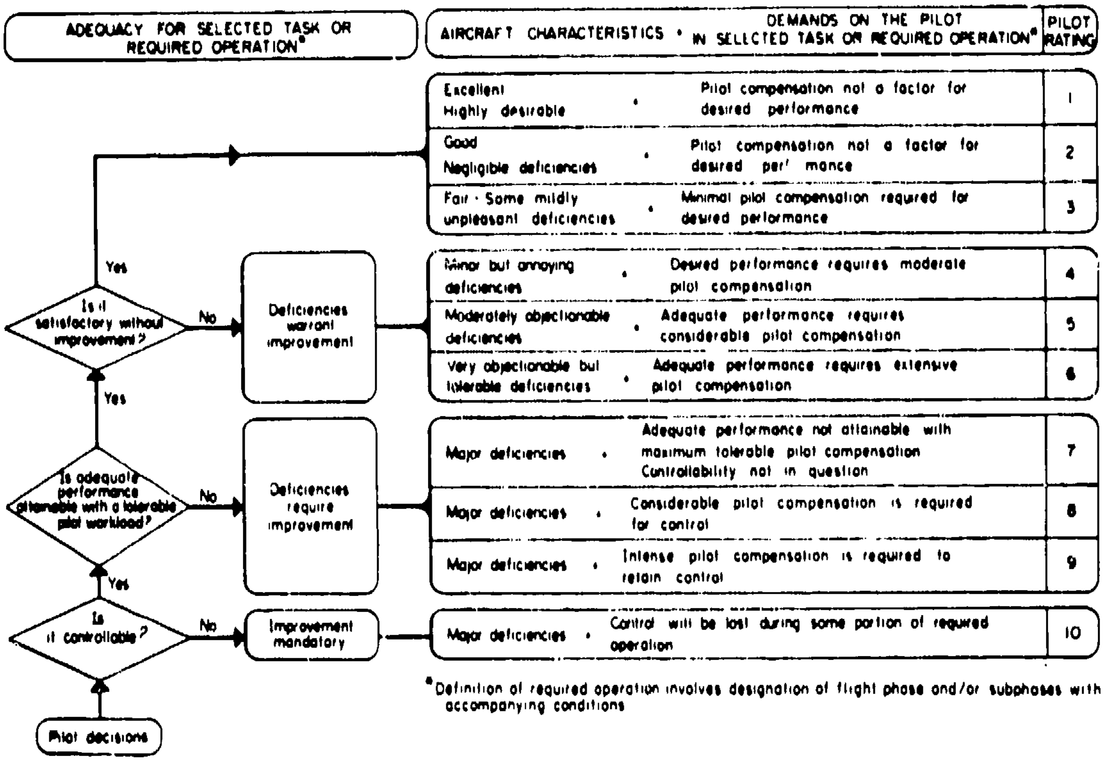


Figure 9. COOPER-HARPER PILOT RATING SCALE

COMMENT CARD

1. Response Characteristics – Predictability, Abruptness
   - Attitude
   - Translation
   - Height control
   - Precision vs. Gross Maneuvering
2. Control Characteristics
   - Control forces and displacements
   - Initial vs. final
   - Harmony (pitch/roll)
3. Special Control Techniques?
4. Task Performance? Workload?
   - Tracking X-Y
   - Tracking Y-Z
   - Landing task
5. Effects of Turbulence?
6. Summary
   - Good Features
   - Objectionable Features
   - Pilot Ratings (Tracking/Landing)

Figure 10. PILOT COMMENT CARD

summary of the pilot comments given in Appendix II must be consulted to obtain a clear understanding of the configuration's suitability for the task.

3.7 DATA ACQUIRED

The data acquired from this experiment falls into the following categories:

1. Pilot ratings and comments
2. Aircraft response
3. Tracking performance

Data on aircraft responses were required to estimate the achieved simulated characteristics; the identification procedures are summarized in Appendix V. Statistical analyses of control utilization were performed and are discussed in Section 4; the raw data are contained in Appendix V.

3.8 EVALUATION SUMMARY

Two Calspan research pilots were used in this program. Their background and experience and the distribution of flight hours is summarized in Table 2. A total of 40.5 hours was flown in this research program. Calibration records were generally taken during evaluation flights so separation of hours into evaluations and calibrations is not possible. Approximately four hours were flown by a Navy LAMPS-qualified pilot for the purpose of simulation development and validation. A total of 111 evaluations of 43 different flight control configurations was obtained in this program.

TABLE 2

QUALIFICATIONS OF EVALUATION PILOTS

PRIMARY PILOT:	Approximately 4000 hours total flying time, currently certified as an airline transport pilot, multi-engine land with commercial single engine land and sea, glider and helicopter endorsements, and certified flight instructor with airplane single and multi-engine land and instrument ratings.
SECOND PILOT:	Over 25 years as a military and civil pilot in over 40 aircraft types and over 8000 pilot hours; holds the following FAA ratings: commercial single and multi-engine land, instrument, helicopter, helicopter instrument, and single and multi-engine aircraft and instrument flight instructor.

Section 4
EXPERIMENT RESULTS

4.1 CALIBRATION OF CONFIGURATION DYNAMICS

The design of augmented evaluation configurations for this experiment was based on a linearized small perturbation model of X-22A hover/low speed dynamics obtained during a previous experiment (Reference 8). Because this model was derived from a fairly limited data base, extensive calibration data were recorded during the current program to ensure that the closed-loop dynamics were accurately known.

System calibration employed an advanced parameter identification technique developed at Calspan (References 13 and 14) to determine the coefficients of a constant coefficient transfer function model of the X-22A state responses to pilot control commands. The calibration procedure and results are described in more detail in Appendix IV. The following subsections summarize the results for the horizontal and vertical dynamics.

4.1.1 Identified Pitch and Roll-Translational Dynamics

As described in Appendix IV,third order dynamical models were employed for identification of the pitch/translational and roll/translational dynamics of the X-22A. The identification results indicated that,in general, the achieved translational dynamics exhibited higher bandwidth (i.e., shorter path mode time constant) and lower steady state gain than the nominal or design values. These discrepancies are primarily attributable to the fact that the unaugmented X-22A has significantly higher pitch and roll control sensitivities (M_{δ_e} and L_{δ_a}) than those used in the system design. As a result, the effective gain for the attitude and velocity feedback was higher than anticipated resulting in higher frequency closed-loop roots. The root loci of Figure 11 illustrate the effect of higher control sensitivity on the closed-loop dynamics of a typical TRC configuration.

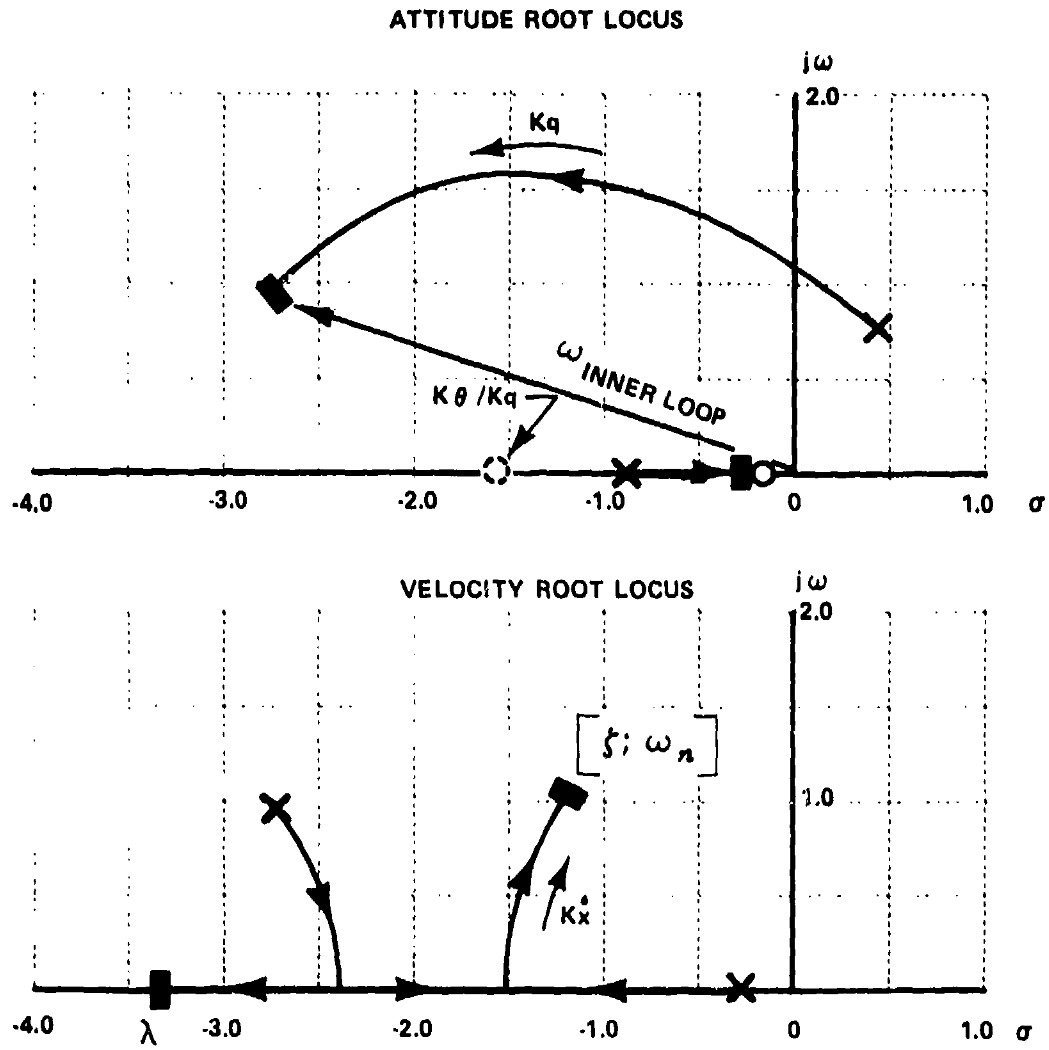


Figure 11 ROOT LOCI FOR ATTITUDE AND VELOCITY CLOSURES WITH HIGHER CONTROL SENSITIVITY (LOOP GAIN)

Table 3 summarizes the transfer characteristics of attitude and velocity for the TRC configurations. The notation employed is:

$$K(s + \lambda)(s^2 + 2\zeta\omega_n s + \omega_n{}^2) \rightarrow K(\lambda)[\zeta;\omega_n]$$

The nominal or design values of path mode time constant and steady state velocity gain are also tabulated for comparison with the characteristics actually achieved. As can be seen from TAble 3, the greatest differences from nominal characteristics exist in the lateral axis for large path mode time constants. The effect of these differences is somewhat faster responses but lower steady state gain (ft/sec/in.) in the lateral axis compared to the longitudinal axis. To assess the possible significance of this mismatch, the pilot commentary was surveyed to determine the frequency of occurrence of complaints relating to lack of control harmony. Evaluations with specific complaints are summarized in Table 4.

Somewhat surprisingly, it is observed that complaints of disharmony are concentrated on low path mode time constant configurations rather than the high path mode time constant configurations as would be expected. The poor pilot ratings and complaints of disharmony for evaluation 219B are attributable to control limiting. Few of the simulated configurations known to exhibit control disharmony were cited for this problem. Likely, with long path mode time constants, other control problems masked the significance of longitudinal/lateral static gain mismatch. It is concluded that this control disharmony had little impact on the flying qualities results of this experiment.

4.1.2 Identification of Height Dynamics

As discussed in Section 2.2.3, two types of height augmentation were employed in this experiment. The simpler control implementation was comprised of augmentation of vertical inertial rate damping by feedback of $\dot{z}$ to the collective controller producing a vertical rate command system. The more complex system, a psuedo model following implementation, added altitude feedback and an integral-proportional command prefilter to yield a vertical rate command with altitude hold system. Feedback and command gains were designed

TABLE 3(a)

COMPARISON OF NOMINAL AND ACTUAL

TRANSFER CHARACTERISTICS (LONGITUDINAL)

NOMINAL			ACTUAL				
Inner Loop ω_n	$T_{\dot{x}}$	$K_{\dot{x}_c}$	$T_{\dot{x}}$	$K_{\dot{x}_c}$	Char. Roots	Num. x/δ_{ES}	Num. θ/δ_{ES}
2.0	1.50	2.6	1.39	2.5	(3.12) [0.62;1.41]	-1.69(9.12)	.48(.16)
"	2.00	4.0	1.89	3.8	(2.83) [0.85;1.19]	"	"
"	2.50	5.4	2.37	5.1	(0.78) (1.50) (2.57)	"	"
"	3.00	6.7	2.86	6.4	(0.51) [0.99;2.18]	"	"
"	3.50	8.0	3.28	7.3	(0.41) [0.98;2.27]	"	"
"	4.00	9.4	3.66	8.3	(0.35) [0.97;2.31]	"	"
2.5	1.50	2.0	1.40	1.9	(3.49) [0.78;1.53]	"	"
"	2.00	2.9	1.92	2.8	(3.10) (1.83) (0.97)	"	"
"	2.50	3.8	2.40	3.7	(0.59) [0.99;2.67]	"	"
"	3.00	4.6	2.83	4.3	(0.46) [0.98;2.78]	"	"
"	3.00	4.6	2.83	4.3	(0.46) [0.98;2.78]	"	"
"	3.50	5.5	3.27	5.0	(0.38) [0.97;2.84]	"	"
"	4.00	6.2	3.68	5.2	(0.32) [0.97;2.88]	"	"
3.0	1.50	1.5	1.44	1.5	(3.76) [0.96;1.66]	"	"
"	2.00	2.2	1.91	2.1	(0.76) [0.99;3.12]	"	"
"	2.50	2.8	2.40	2.7	(0.53) [0.98;3.29]	"	"
"	3.00	3.4	2.85	3.2	(0.42) [0.97;3.38]	"	"
"	3.50	3.9	3.25	3.7	(0.36) [0.96;3.42]	"	"
"	4.00	4.5	3.64	4.0	(0.32) [0.96;3.46]	"	"

NOTE: $K(s+\lambda)(s^2+2\zeta\omega_n s+\omega_n^2) \rightarrow K(\lambda)[\zeta;\omega_n]$

TABLE 3(b)
COMPARISON OF NOMINAL AND ACTUAL
TRANSFER CHARACTERISTICS (LATERAL)

NOMINAL			ACTUAL				
Inner Loop ω_n	$T_{\dot{y}}$	$K_{\dot{y}_c}$	$T_{\dot{y}}$	$K_{\dot{y}_c}$	Char. Roots	Num. $\dot{y}/\delta_{AS}$	Num. ϕ/δ_{AS}
2.0	1.50	2.8	1.34	2.3	(4.21) [0.66;1.40]	2.16(8.77)	0.59(0.18)
"	2.00	4.1	1.70	3.2	(4.09) [0.81;1.21]	"	"
"	2.50	5.5	2.01	4.0	(4.03) [0.92;1.09]	"	"
"	3.00	6.8	2.26	4.5	(3.99) (1.13) (0.93)	"	"
"	3.50	8.0	2.48	5.1	(3.96) (1.42) (0.66)	"	"
"	4.00	9.2	2.67	5.4	(3.94) (1.55) (0.57)	"	"
2.5	1.50	2.1	1.34	1.7	(4.40) [0.83;1.57]	"	"
"	2.00	3.0	1.70	2.4	(4.24) (1.51) (1.25)	"	"
"	2.50	3.9	1.98	2.8	(4.15) (2.08) (0.78)	"	"
"	3.00	4.6	2.23	3.2	(4.09) (2.30) (0.63)	"	"
"	3.50	5.5	2.47	3.6	(4.03) (2.44) (0.54)	"	"
"	4.00	6.2	2.67	3.9	(3.98) (2.55) (0.48)	"	"
3.0	1.50	1.7	1.34	1.4	(4.48) [0.99;1.74]	"	"
"	2.00	2.3	1.68	1.8	(4.23) (2.79) (0.89)	"	"
"	2.50	2.9	1.98	2.2	(3.96) (3.27) (0.67)	"	"
"	3.00	3.5	2.23	2.5	(0.57) [0.99; 3.68]	"	"
"	3.50	4.1	2.46	2.7	(0.50) [0.99; 3.73]	"	"
"	4.00	4.7	2.68	3.0	(0.45) [0.99; 3.77]	"	"

NOTE: $K(s+\lambda)(s^2+2\zeta\omega_n s+\omega_n^2) \rightarrow K(\lambda)[\zeta;\omega_n]$

TABLE 4

SUMMARY OF CONFIGURATIONS

CITED FOR CONTROL DISHARMONY

Nominal Path Mode Time Constant (sec)	Flt/Eval. No.	Pilot Ratings X-Y-Z/Lndg.	Comments
3	206A	3/2	Forces may be little bit high laterally
2.5	206C	7/7	Sometimes roll felt heavier than pitch
2.5	213B	7/4	Hovering sideslipped – roll felt higher than pitch
3	219B*	9/6	Felt less responsive in roll than pitch
1.5	220B	6/4	(Harmony) maybe a prob- lem – couldn't define
1.5	221A**	5/4	Lateral forces got a little bit high
2.0	224A	6/3	X translation took more force than Y
1.5	224B	4/3	Little more force in X than Y

* Roll control power limited.
**Pitch control power limited.

to produce cancellation of the prefilter numerator zero and one of the characteristic roots so that response to throttle commands would be first order. That is:

$$\frac{\dot{z}}{\delta_T} = \underbrace{K_{\dot{z}}\left(\frac{s+\lambda_{\dot{z}}}{s}\right)}_{\text{Prefilter}} \underbrace{\frac{s}{(s+\lambda_{\dot{z}})^2}}_{\substack{\text{Augmented}\\ \text{Vertical}\\ \text{Dynamics}}} = \frac{K_{\dot{z}}}{s+\lambda_{\dot{z}}}$$

For each of these systems, the identification model employed was first order. Thus, in the case of the vertical rate command system, the identified model was of the same order as the actual aircraft vertical dynamics. In the case of the vertical rate command/altitude hold system, the identified model is exact only if prefilter and characteristic equation zero pole cancellation takes place exactly as intended. For this system then, the identification model must be viewed as a lower order equivalent system representation. The rationale for using a lower order model was that the design intent was to produce a first order-like response. If this objective was not achieved, the identification process would be unable to produce good time history matches. Therefore, the ability to match the second order control responses with a first order model would substantiate the occurrence of pole-zero cancellation and justify the lower order equivalent system model. The quality of the time history matches shown in Appendix IV validates the achievement of the design goals. Appendix IV summarizes the identification results for the vertical dynamic configurations.

4.2 PILOT RATING RESULTS

4.2.1 Primary Pilot Ratings for Baseline TRC Matrix (Inner Loop ω_n = 2.5 rad/sec)

As discussed in Section 4.1, the long path mode time constant configurations exhibited some lack of harmony between the longitudinal and lateral

axes. Although control disharmony was occasionally cited as a problem, the longest time constant configurations, somewhat suprisingly, were seldom described as exhibiting this problem. Control disharmony has therefore been discounted as a significant factor in the flying qualities results. Since pilot commentary generally indicated that longitudinal control was the most difficult, pilot ratings, in this section, are correlated with the longitudinal dynamic characteristics. The pilot rating data for evaluations of the baseline configuration matrix (inner loop natural frequency 2.5 rad/sec) by the primary pilot are summarized in Figure 12. The axes of this graphical presentation are the longitudinal steady state velocity gain and the equivalent first order path mode time constant described previously. Pilot ratings for repeated evaluations have been averaged and the symbols are shaded to denote the level of flying qualities.

All evaluations in this set, except as noted, were flown with synthetic turbulence on and with vertical augmentation selected to allow focussing on the problems of translational control. Two vertical augmentation systems were employed, each with altitude hold and with command gains of .1 and .15 g's per inch of throttle and velocity response time constants of 2.0 and 1.33 seconds, respectively. Individual pilot ratings together with configuration identifiers for each evaluation in this group are presented in Figures 13 to 16. Each configuration was assigned two pilot ratings. The first rating is for the discrete tracking task on X, Y and Z while the second (in parenthesis) is for the simulated vertical landing. For the summary plot, the worst of these two ratings was used as representative of the overall rating for that configuration.

With the exception of the evaluations of Flight 204, the pilot commentary substantiates that these augmented height dynamics satisfied the objective of satisfactory, unobstrusive flying qualities in the vertical axis. The height control difficulties experienced on this flight are attributed not to the dynamics but rather to a mechanical problem with the throttle detent which made setting the throttle to the zero rate command position difficult.

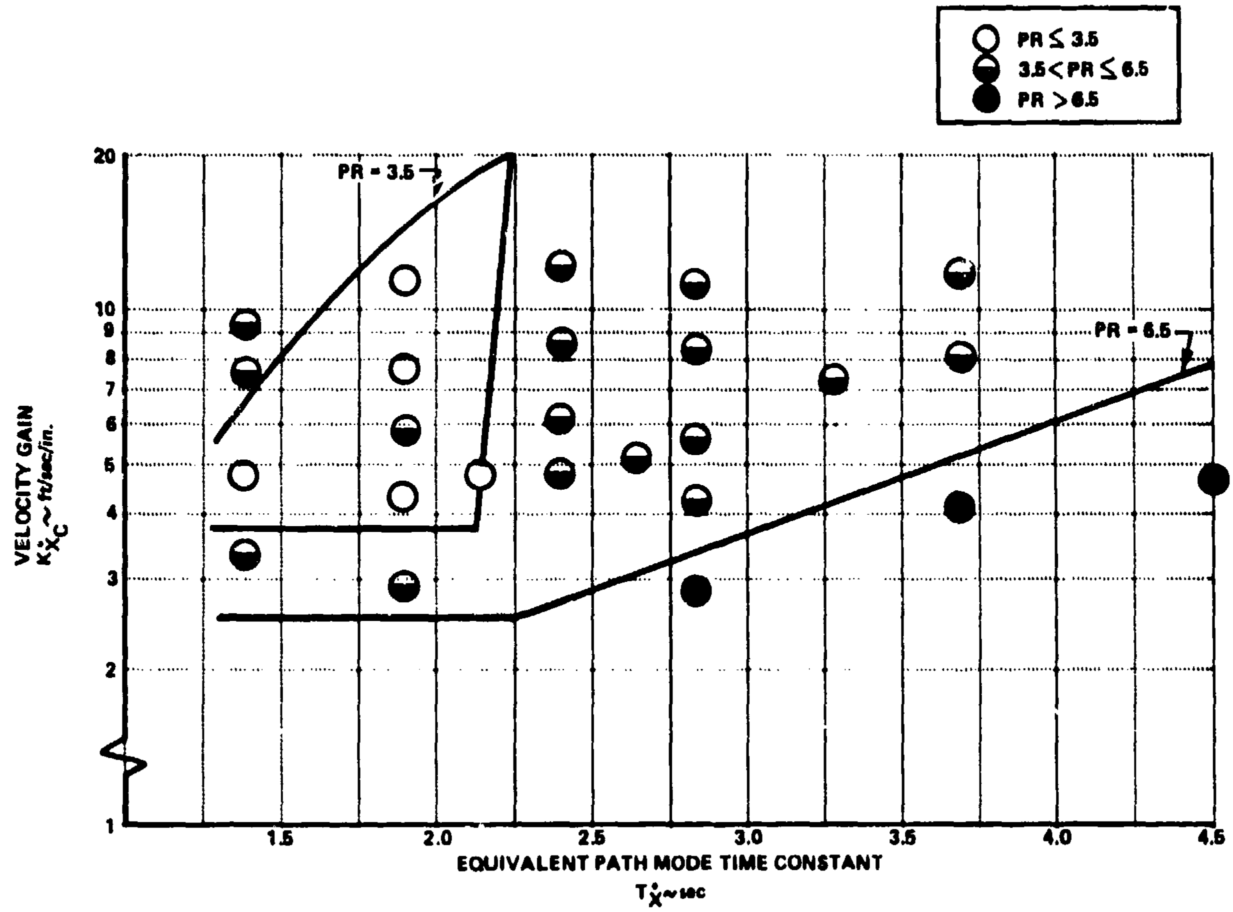


Figure 12 PILOT RATING SUMMARY FOR BASELINE MATRIX (INNER LOOP ω_n = 2.5 r/s) PRIMARY PILOT

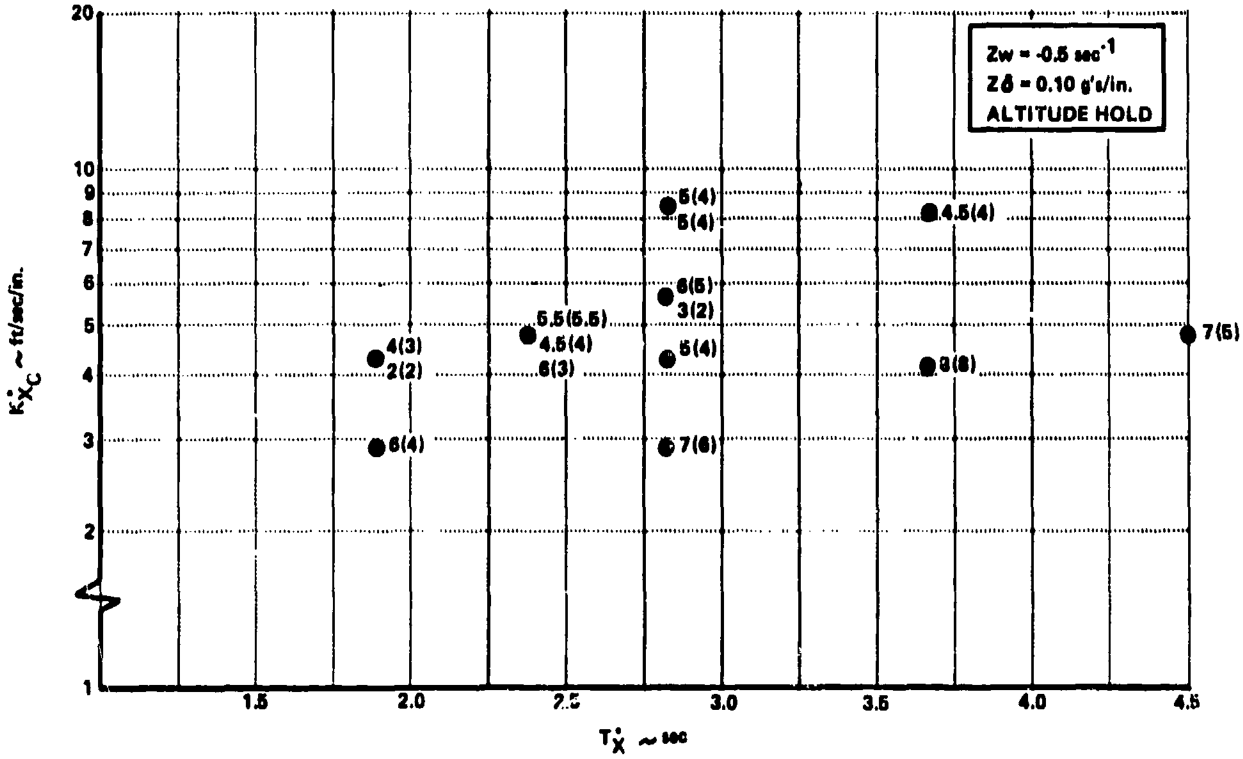


Figure 13 PILOT RATING SUMMARY FOR TRC EVALUATIONS WITH FIRST ALTITUDE AUGMENTATION SYSTEM

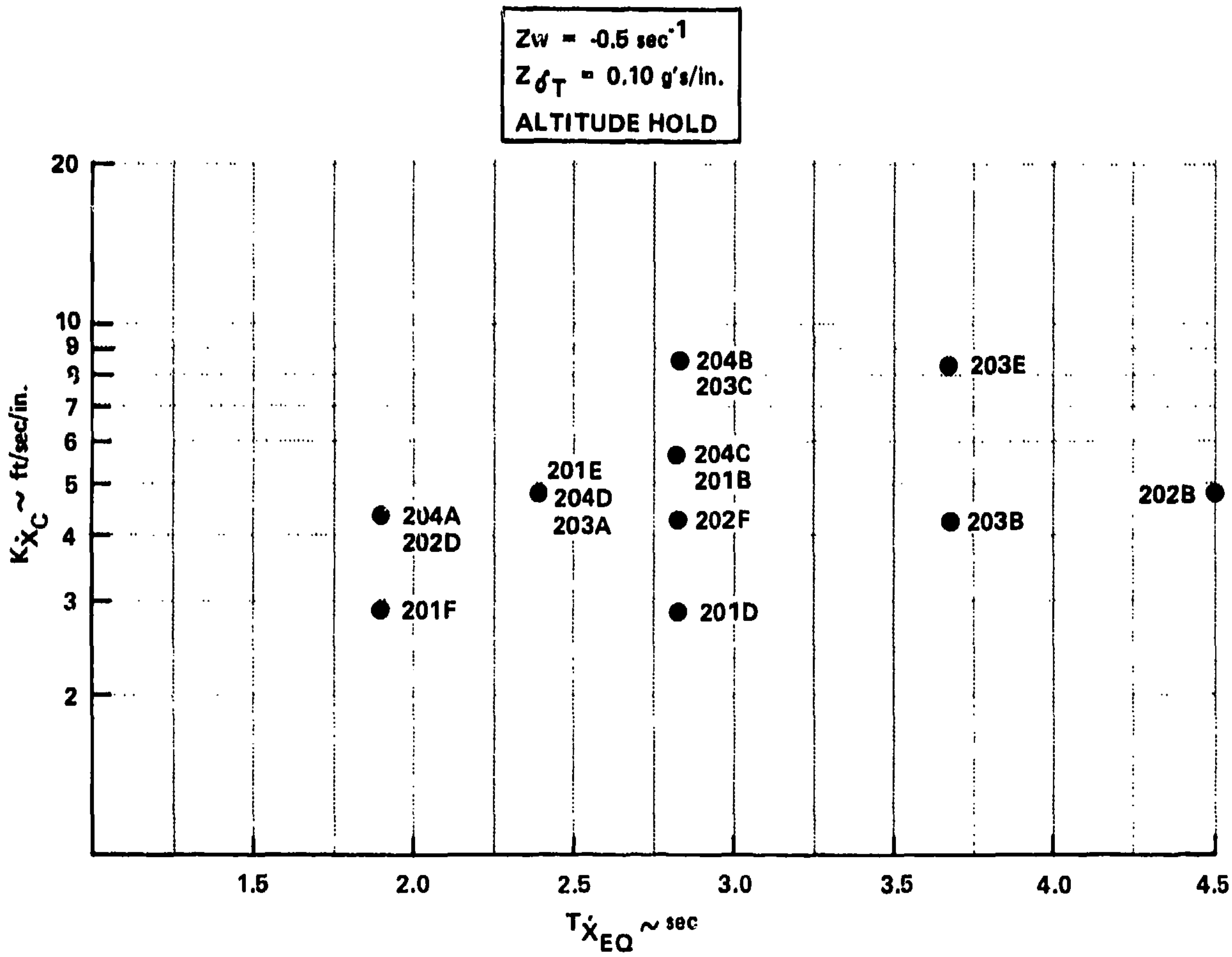


Figure 14 CONFIGURATION IDENTIFIERS FOR TRC EVALUATIONS WITH FIRST ALTITUDE AUGMENTATION SYSTEM

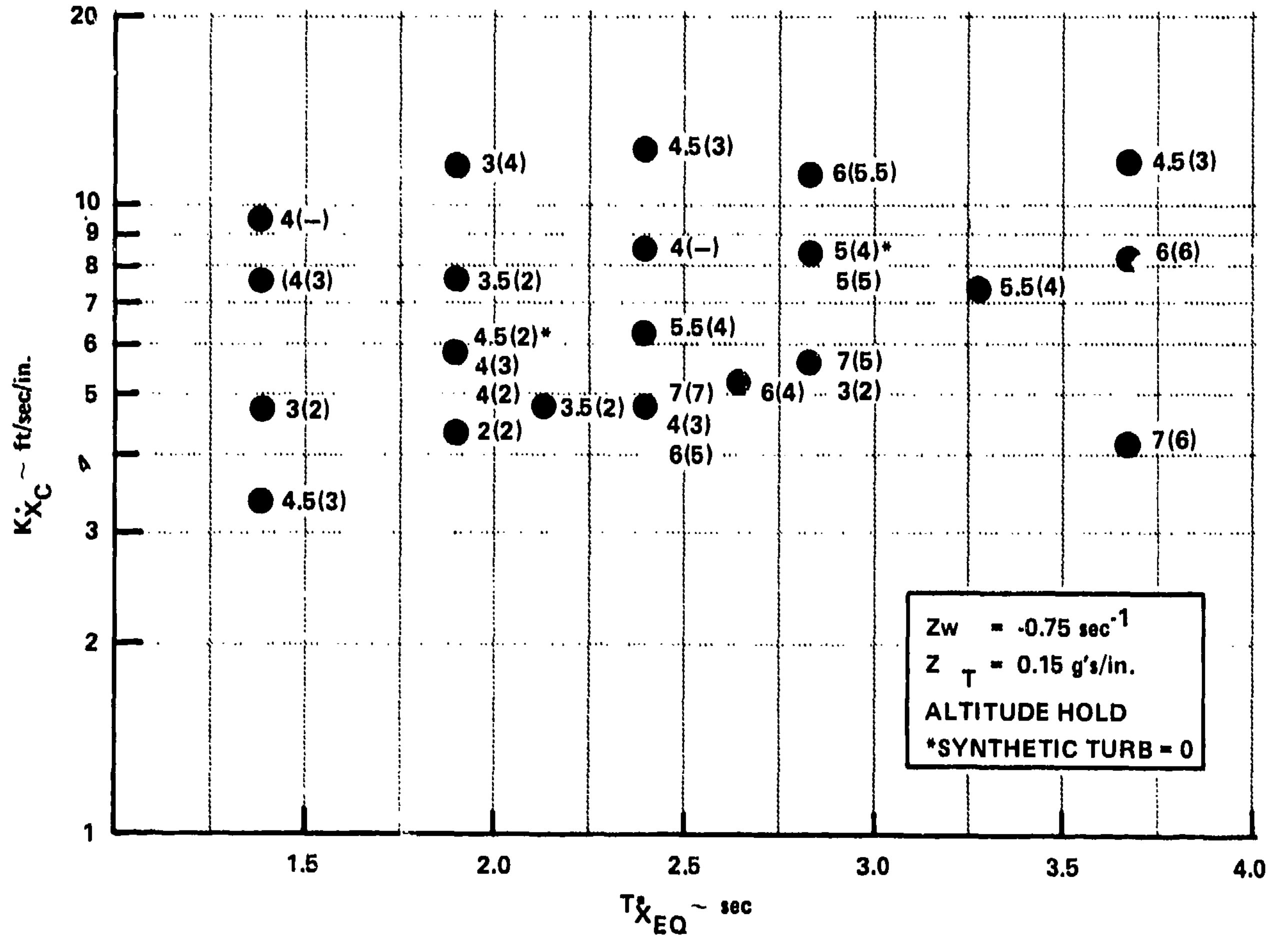


Figure 15 PILOT RATING SUMMARY FOR TRC EVALUATIONS WITH SECOND ALTITUDE AUGMENTATION SYSTEM

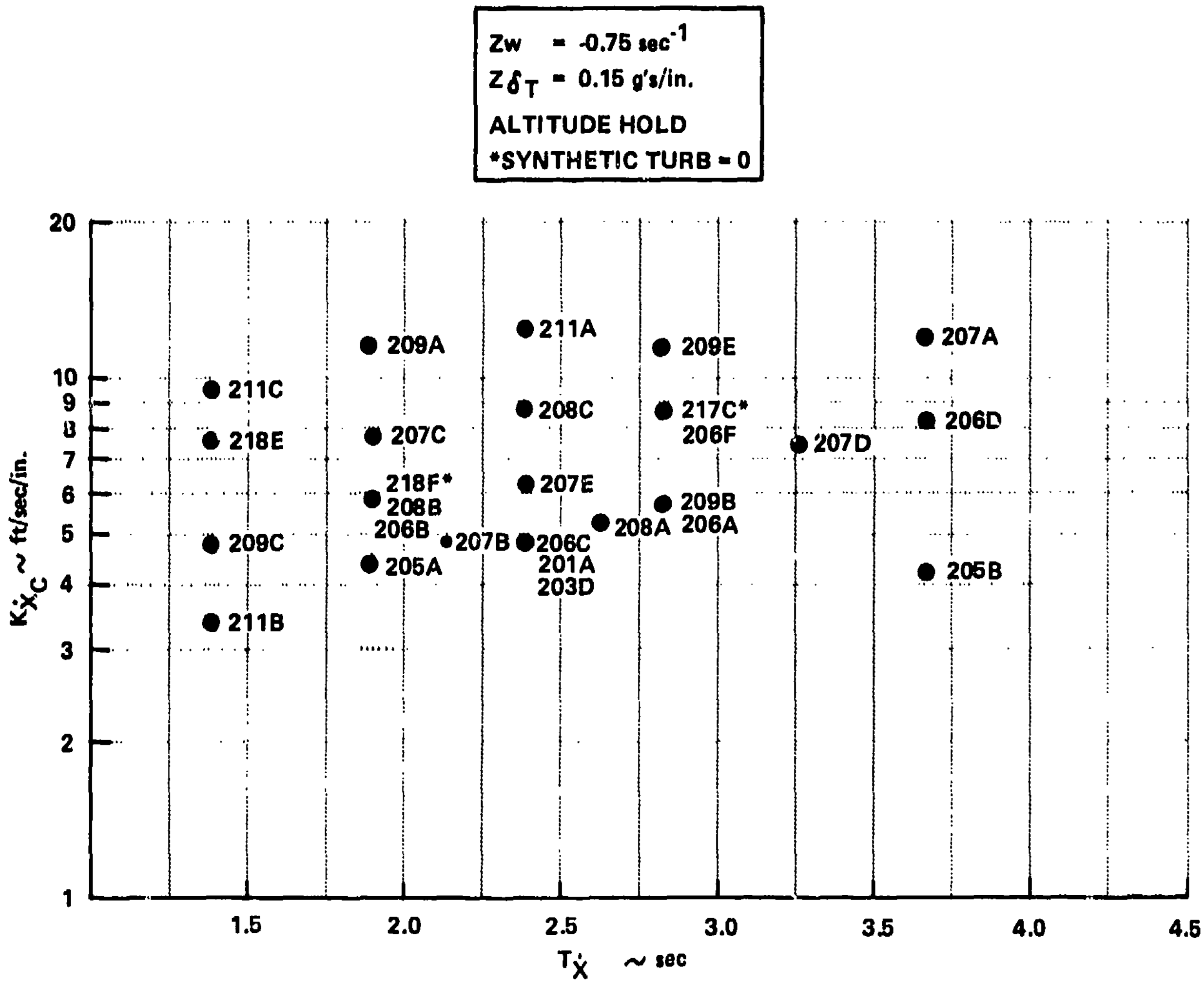


Figure 16 CONFIGURATION IDENTIFIERS FOR TRC EVALUATIONS WITH SECOND ALTITUDE AUGMENTATION SYSTEM

In Figure 12, the lower pilot rating boundaries (PR = 3.5 and 6.5) are associated with excessive control forces and displacements required for maneuvering and define minimum control sensitivity as a function of path mode time constant. The upper boundary (PR = 3.5) is a limit associated with abruptness in attitude response and corresponds roughly to a pitch attitude acceleration of 80 deg/sec^2/in. For velocity gains within these upper and lower bounds, only a limited range of path mode time constants produced satisfactory flying qualities. For a path mode of greater than approximately 2.25 seconds, configurations were judged unsatisfactory because of lack of precision and predictability in velocity and position response. Path mode time constants less than about 1.5 sec have little practical significance because of the large moment control power required for TRC implementation and because of the tendency for the upper and lower flying qualities boundaries to merge rapidly at these low time constants.

In comparison to flying qualities data from other experiments (References 5 and 15) the regions within flying qualities boundaries shown in Figure 12 are relatively small. Figure 17 is a plot of the data of Reference 15 utilizing the parameters of Figure 12. In this experiment, performed on a moving base simulator with real world visual cues, the TRC systems were configured to have characteristic dynamics of the binomial form (all roots of the characteristic equation equal) and are approximately equivalent in system damping to the configurations of this experiment. These data indicate that satisfactory flying qualities can be achieved with both higher maximum and lower minimum velocity command gains than the current experiment. Within the limits of satisfactory command gains, the range of equivalent path mode time constants evaluated was insufficient to define the maximum satisfactory limit although satisfactory ratings were achieved for time constants up to 4.0 sec in the rapid maneuvering task. The data of Reference 5, plotted here as Figure 18, also suggest that path mode time constants up to 4 seconds can provide satisfactory flying qualities. Command gain data from this experiment are not directly applicable to the situation of the current experiment, however, since the evaluations were performed using a sidestick as opposed to a center stick cockpit controller.

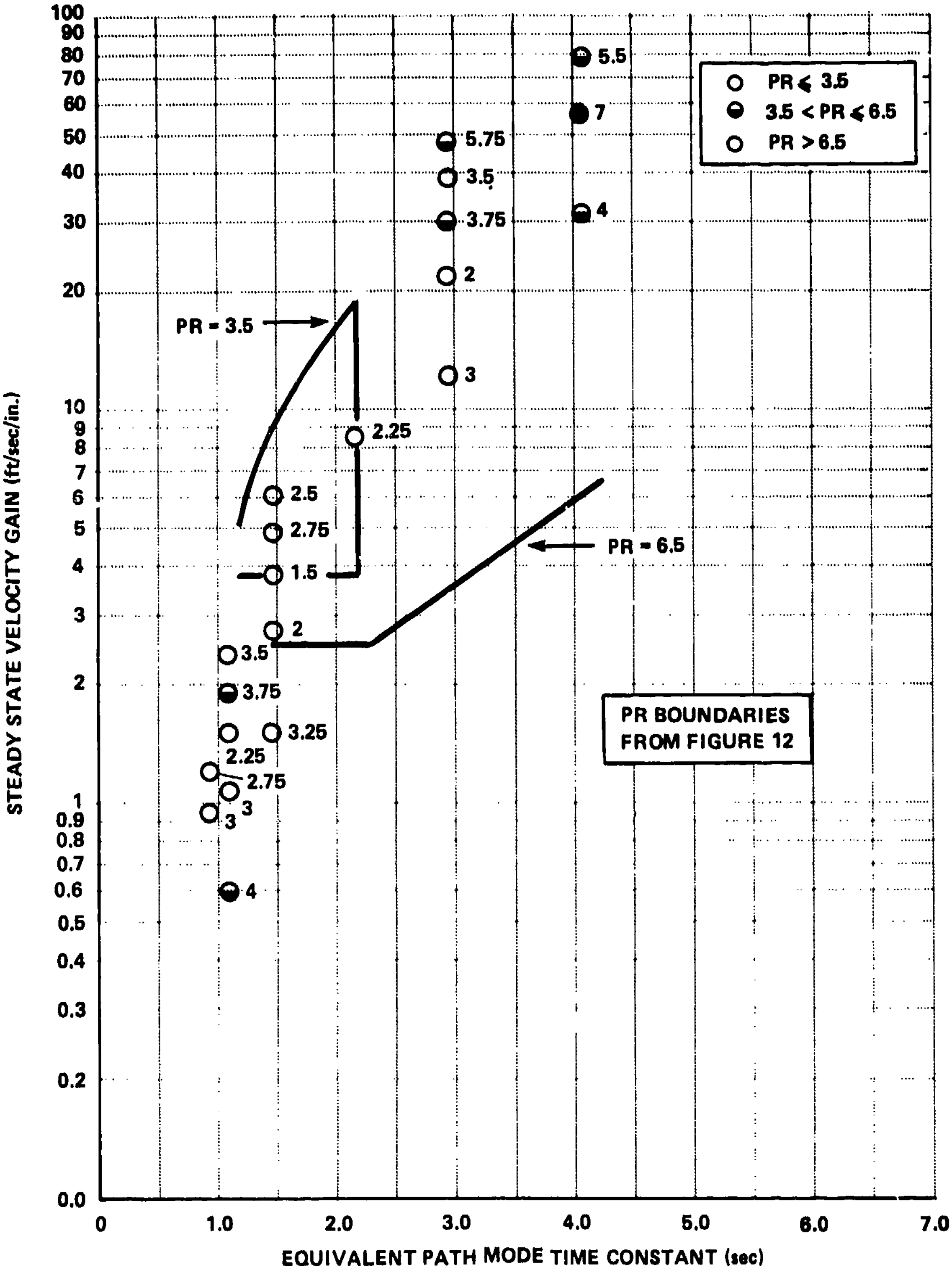


Figure 17a PILOT RATING DATA FROM REFERENCE 15 (STATIONKEEPING MILD MANEUVERING TASK)

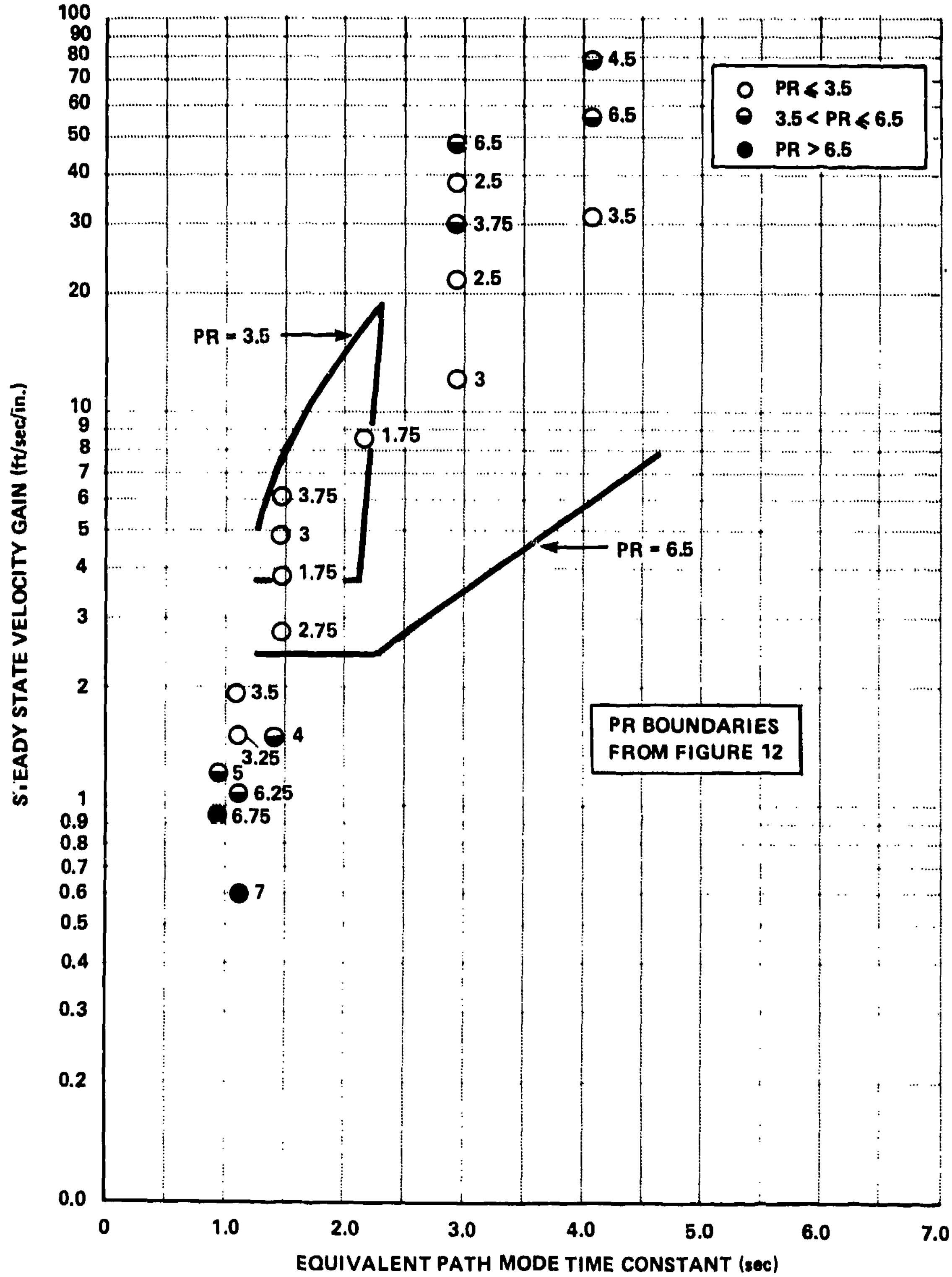


Figure 17b PILOT RATING DATA FROM REFERENCE 15 (RAPID MANEUVERING TASK)

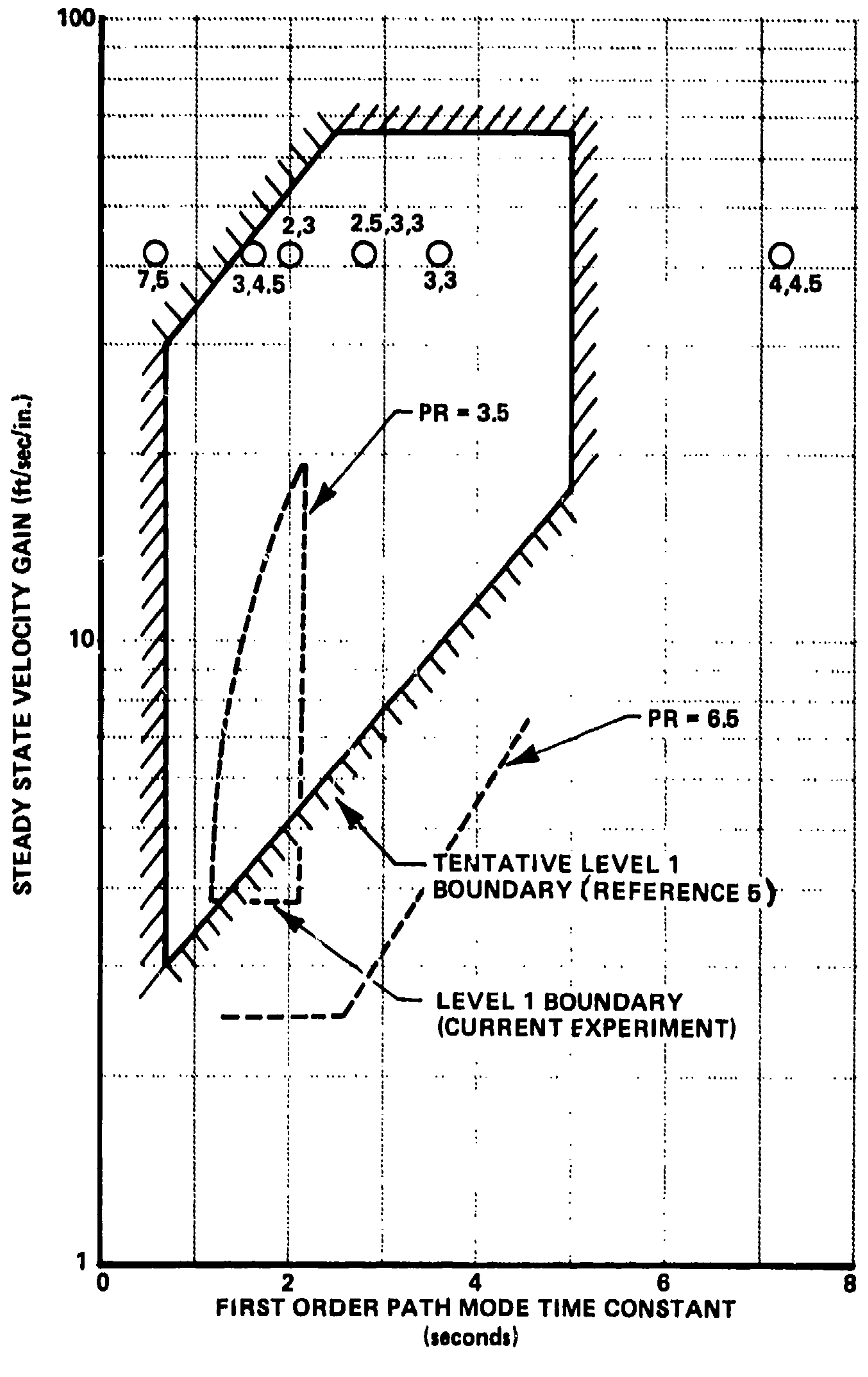


Figure 18 PILOT RATING DATA FOR TRC SYSTEMS USING SIDEARM CONTROL (REFERENCE 5)

The differences observed in the results of these ground simulator experiments and this in-flight experiment cannot be explained with certainty. Motion scaling and "washout", visual field-of-view and resolution and motion amplitude limits in ground simulators are sometimes responsible for flying qualities differences with respect to actual flight characteristics. Likely, significant factors for the current experiment were the explicit display of aircraft position together with the controlled input bandwidth of the discrete tracking task. As a consequence of the high task demands, the limits on command gains and path mode time constants for satisfactory flying qualities were more stringent.

4.2.2 Ratings of Second Pilot

Rating data for the second pilot are presented in Figure 19. Although the pilot ratings indicate a considerably smaller satisfactory region, these results must be viewed in the light of the relatively short exposure of this pilot to the simulation experiment (4 flights). Learning effects are evident in the data in that when configurations from the first flight were repeated on subsequent flights the ratings improved. Furthermore, both pilots are in agreement with respect to the center of the optimum region. It is likely that substantially better agreement would have been achieved if the second pilot had been afforded additional flight time.

4.2.3 Pilot Technique

In order not to prejudice pilot techniques, the pilots were briefed at the start of the program regarding the flight control mechanizations to which they would be exposed. It was pointed out that the conventional pitch and roll stick would now directly command inertial velocity as opposed to the more usual angular rate or attitude command systems with which they were familiar. Furthermore, they were instructed that pitch and roll attitude were now dependent states, manipulated by the flight control system to achieve the commanded inertial velocity. In addition, although the pilots were told the general range of the parameter variations to be evaluated, they were not in-

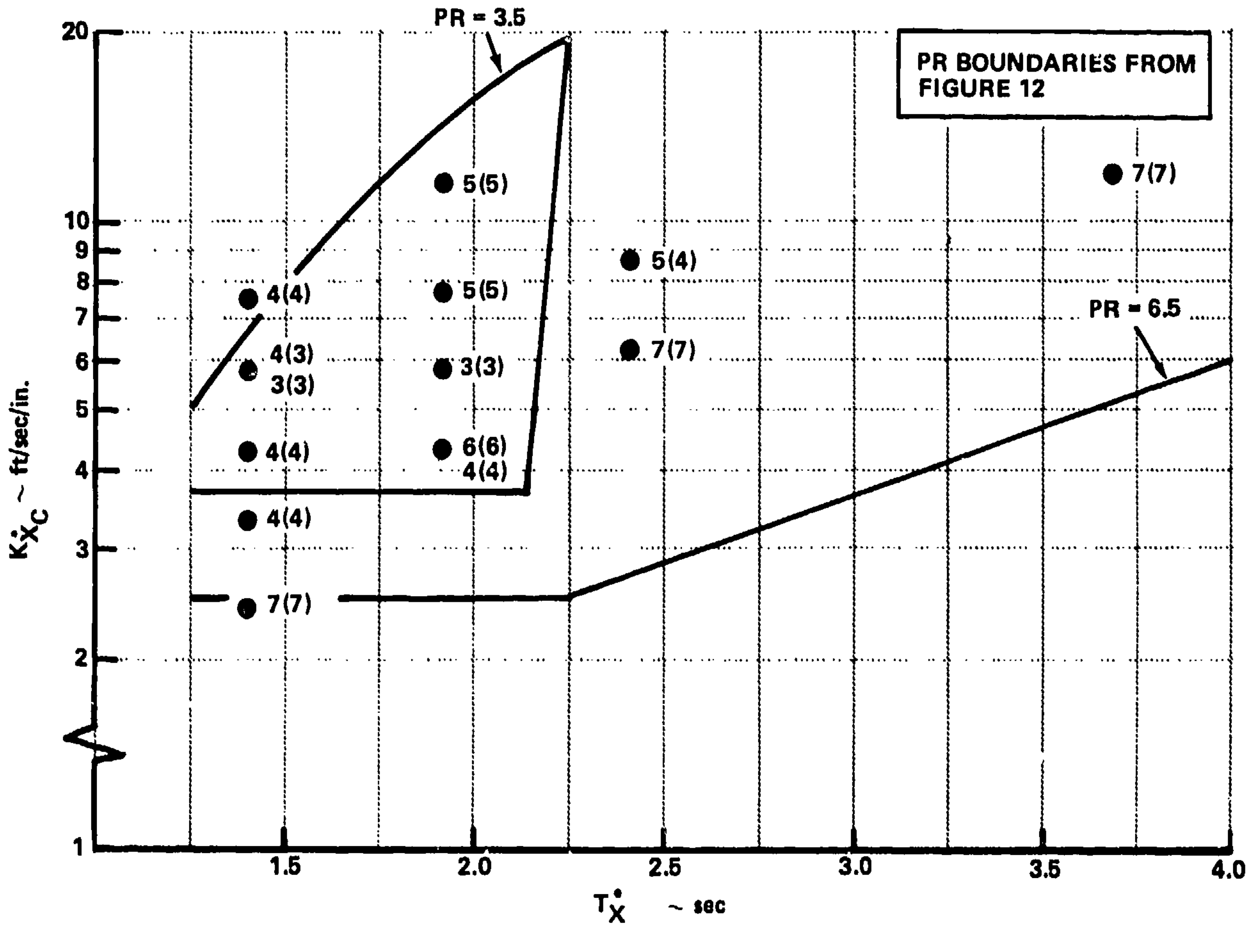


Figure 19a PILOT RATING SUMMARY FOR BASELINE MATRIX (INNER LOOP ω_n = 2.5 r/s) SECOND PILOT

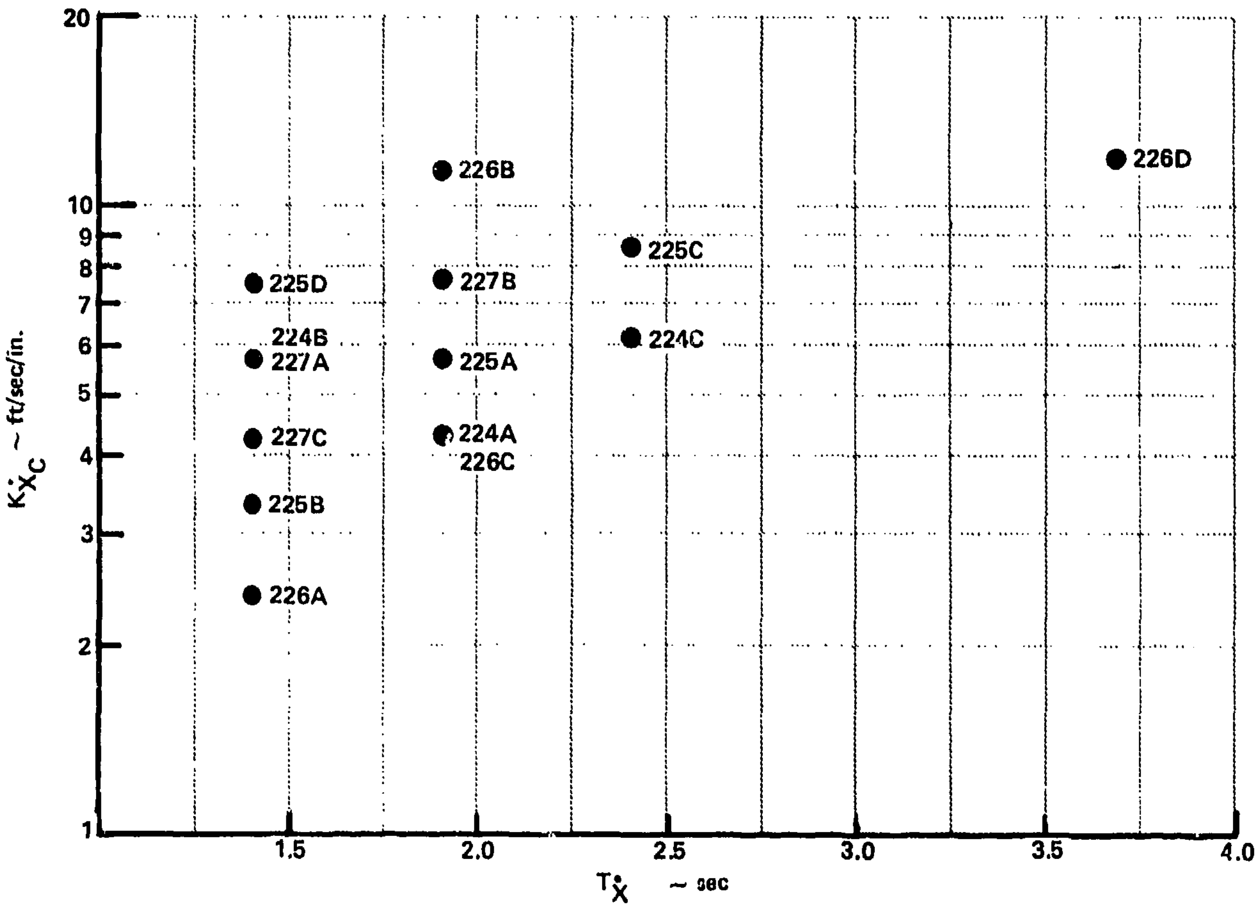


Figure 19b CONFIGURATION IDENTIFIERS FOR BASELINE MATRIX (INNER LOOP ω_n = 2.5 r/s) SECOND PILOT

formed of the specific configuration for each evaluation. The pilots were not directed to any specific control technique but, instead, were encouraged to be flexible and to describe in their comments any unusual aspects of the technique employed for each configuration.

Although the pilot rating data for the primary and secondary pilots are in general similar, it is clear from the recorded pilot commentary that the two pilots were, at least for some configurations, adapting different control techniques. For example, the primary pilot, in describing the flying qualities and his control technique, used phrases like "poor attitude response predictability," "can't find trim attitude for hover," "forces initially light then heavy up." The latter comment, in particular, suggests that the pilot was attempting to control the inner loop and maintain a constant pitch attitude by increasing stick deflection to compensate for bleed-off by the flight control system. In contrast, the second pilot tended to concentrate on outer loop (position) control. His commentary references attitude only when its response was large or abrupt. The pilot ratings for a long path mode time constant configuration ($K_{\dot{x}} = 13.0$, $T_{\dot{x}} = 4$) tend to substantiate this hypothesis. The second pilot's rating was 7 while the primary pilot's rating was 4.5. Configurations with a long path mode time constant (4 to 5 seconds) have very little velocity feedback and, in effect, resemble attitude command systems in their response characteristics. It is surmised that with attitude-like dynamics, the primary pilot's technique of inner loop control allowed for adequate task performance albeit at the expense of considerable pilot compensation. The second pilot, on the other hand, found that adequate performance was not attainable. Clearly, verification of these conclusions requires more detailed analysis of pilot control activity and may be a fruitful area for application of pilot model identification techniques.

4.2.4 Ground-Referenced Task Evaluations

A small group of configurations from the baseline matrix were evaluated in a ground-referenced task for comparison with HUD task evaluations. The task was comprised of forward and rearward translations parallel to an airport taxi-way and lateral translations between the edges of the taxi-way (approx-

imately 75 feet in width). For flight safety reasons, only limited vertical maneuvering was attempted. In general, the maneuvering with all configurations was more aggressive and distances traveled in translating, stopping and reversing tended to be longer than in the HUD task. Attitude excursions, angular rates, velocity and control inputs were all larger as well. Pilot confidence in the better TRC configurations was apparent. At one point, a translation at 18 ft/sec backwards along the taxi-way was recorded, a maneuver that would not be attempted in the basic X-22A with rate SAS.

The pilot rating results together with the flight number identifiers are presented in Figures 20 and 21. The boundaries for PR = 3.5 and 6.5 from the baseline configuration matrix (Figure 12) are plotted on Figure 20 for reference. The ratings and pilot commentary for the configurations in the vicinity of the PR = 3.5 boundary suggest a pilot preference for higher control sensitivities than in the HUD task and, with satisfactory sensitivities, a tolerance for longer path mode time constants. Commentary for configurations 214A, 218G and 212F cites high control force as a major contributor to the pilot rating.

The ratings for configurations 212D and G ($T_{\dot{x}}$ = 2.8 sec) appear somewhat anomalous in that 212D is mildly "crabbed" for high control forces but received a satisfactory pilot rating. Configuration 212G with approximately 50 percent higher command gain (i.e., 33 percent lower forces) but the same time constant is now crabbed for a dynamics problem, poor settling of attitude following a control input and a tendency to "dance around." In part, these anomalies may be attributable to changes in the pilots' performance standard.

In summary, these evaluations, although limited in extent, indicate that the region of satisfactory flying qualities in a visual ground-referenced task would exhibit higher minimum control sensitivities and higher maximum path mode time constants than in the more precise HUD task.

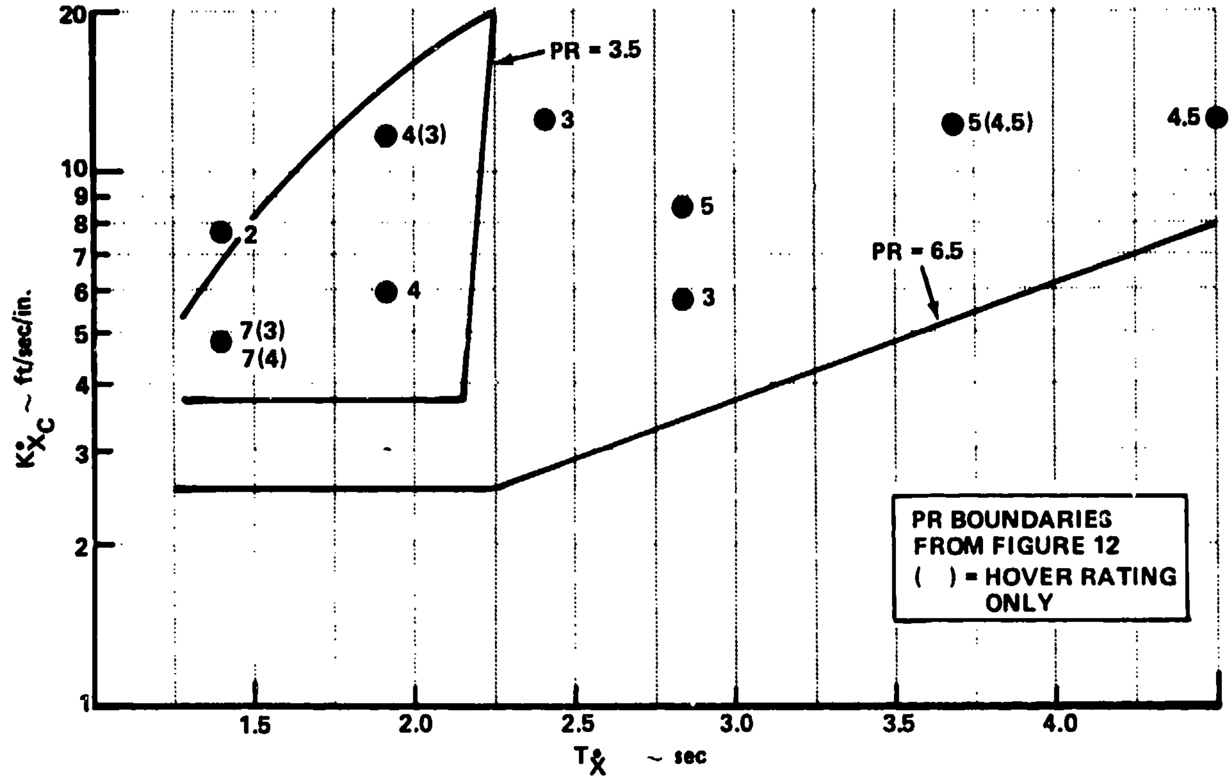


Figure 20 PILOT RATING SUMMARY FOR GROUND REFERENCED TASK (INNER LOOP ω_n = 2.5 r/s) PRIMARY PILOT

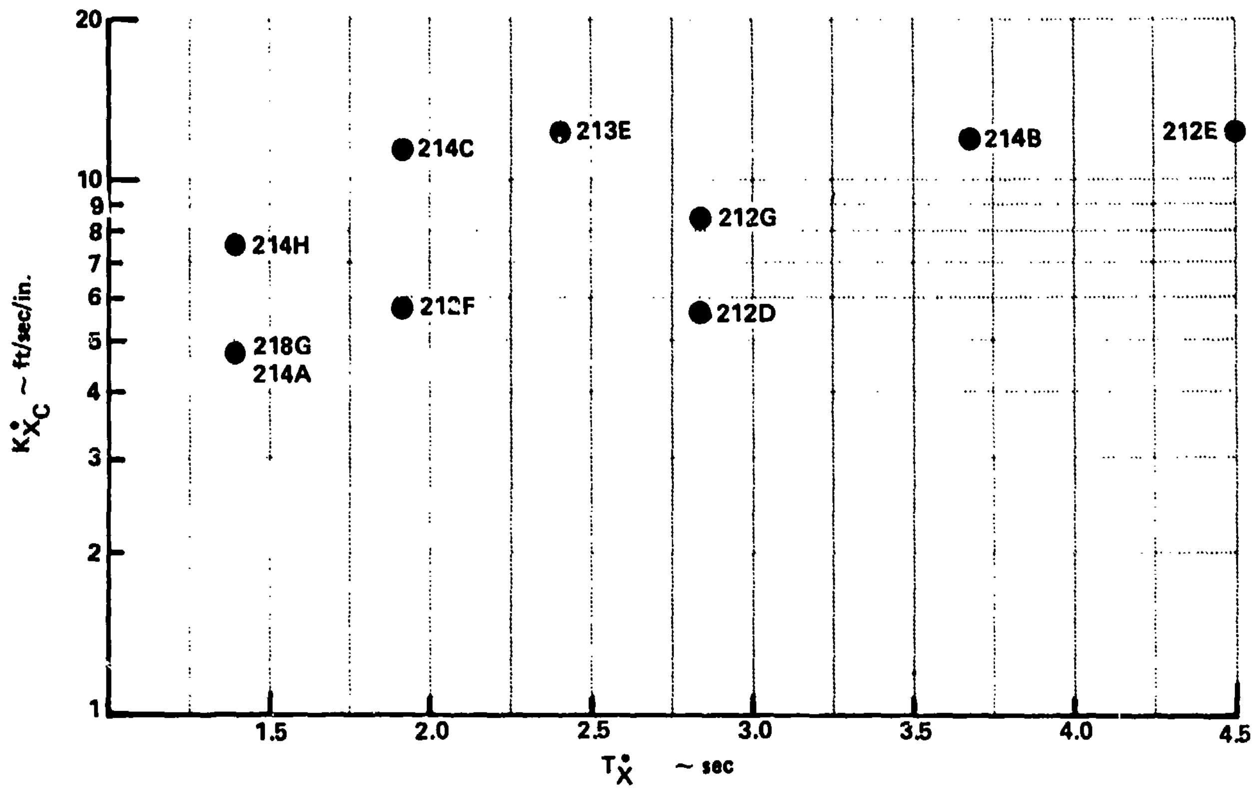


Figure 21 CONFIGURATION IDENTIFIERS FOR GROUND REFERENCED EVALUATIONS (INNER LOOP ω_n = 2.5 r/s) PRIMARY PILOT

4.2.5 Effect of Inner Loop Frequency

This group of evaluations examined TRC configurations having inner loop natural frequencies both higher and lower than the baseline matrix (inner loop ω_n = 2.5 rad/sec). Recall from the analysis of Section 2.2.1 that, at a given path mode time constant, configurations with higher frequency inner loop altitude dynamics exhibit lower susceptibility to turbulence but higher attitude abruptness than systems with low frequency inner loops. The purpose of these variations, therefore, was to determine the sensitivity of pilot rating and task performance to these factors and hence to determine the importance of inner loop frequency as an additional TRC flying qualities parameter.

The range of steady state velocity gains and path mode time constants for these additional configurations were selected to span the region of satisfactory flying qualities defined by the baseline matrix. Although only a limited number of configurations were evaluated, the data indicate that inner loop frequencies both higher and lower than the baseline value result in relative degradation of flying qualities. As can be seen from the plot of pilot ratings for the low frequency attitude loop systems (Figure 22), the flying qualities are generally degraded compared to the baseline configurations. Of this group, only one configuration (220C) received a satisfactory rating. Since this evaluation was flown with no synthetic turbulence and with low ambient winds and turbulence, this rating is not representative but rather reflects the best rating achievable under ideal ambient conditions. Referring to the excerpted pilot comments of Table 5, it can be seen that the major complaints relate to position drift and excitation of attitude perturbations by turbulence.

For configurations with higher frequency inner loop attitude dynamics, the degradation in flying qualities appears to be attributable to abruptness in the attitude response (see Figure 23 and the pilot comment summary of Table 6). In effect, the satisfactory flying qualities region tends to shrink because of a lowering of upper Level 1 boundary associated with attitude

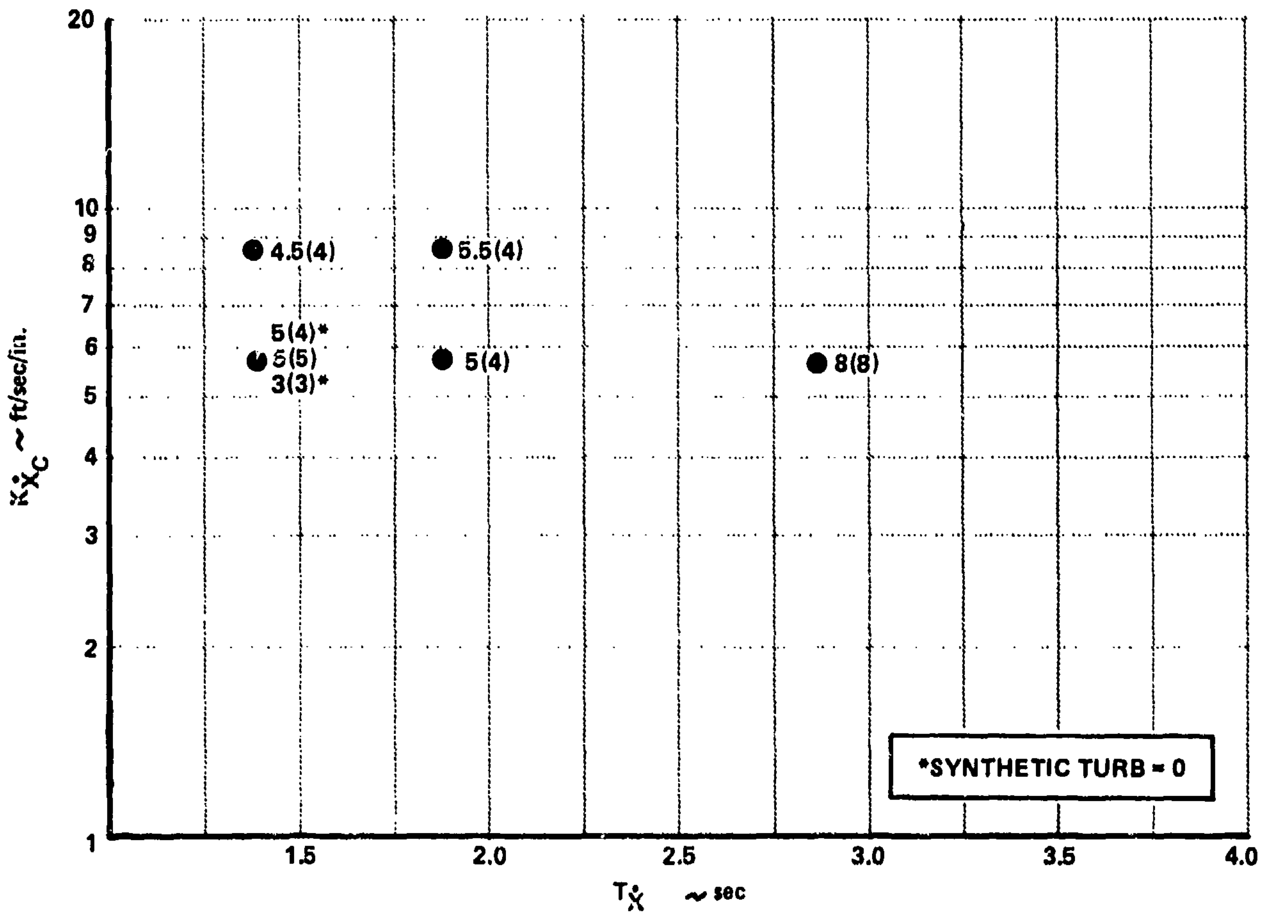


Figure 22a PILOT RATINGS FOR TRC SYSTEMS WITH INNER LOOP ω_n = 2.0 r/s

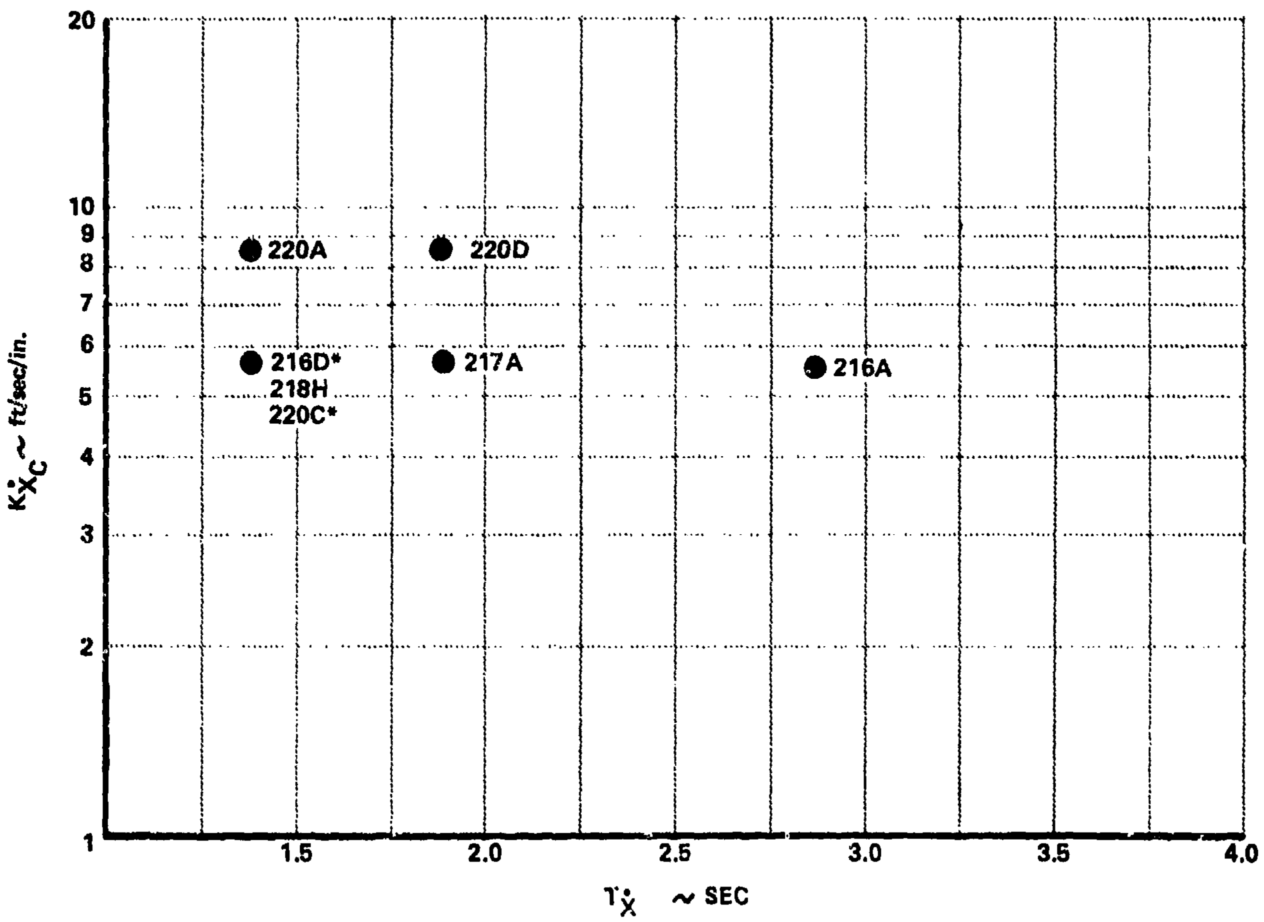


Figure 22b CONFIGURATION IDENTIFIERS FOR TRC SYSTEMS WITH INNER LOOP ω_n = 2.0 r/s

TABLE 5

PILOT COMMENT SUMMARY FOR TRC SYSTEMS

WITH ω_n (INNER LOOP) = 2.0 RAD/SEC

Flt/Config.	Pilot Ratings	Comments
220A	4.5/4	Airplane a little jerky, tendency to drift.
216D	5/4	Trouble finding attitude to hover, didn't feel connected in pitch attitude.
218H	5/5	Problems stopping translation, danced around in attitude, tended to drift.
220C	3/3	Slight tendency to drift.
220D	5.5/4	Poor predictability, airplane danced around without inputs.
217A	5/4	Drifted, sluggish.
216A	8/8	Sluggish, large control displacements

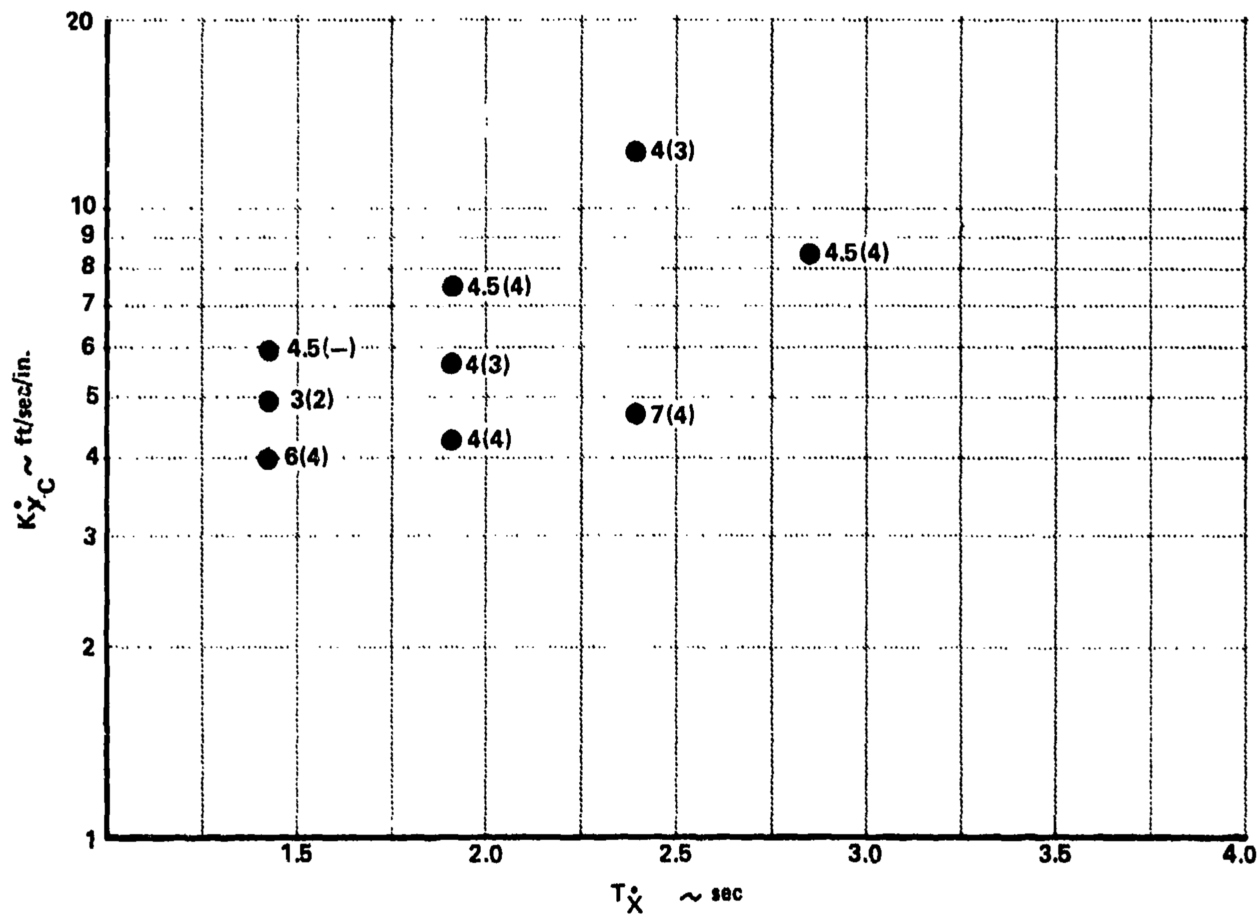


Figure 23a PILOT RATINGS FOR TRC SYSTEMS WITH INNER LOOP ω_n = 3.0 r/s

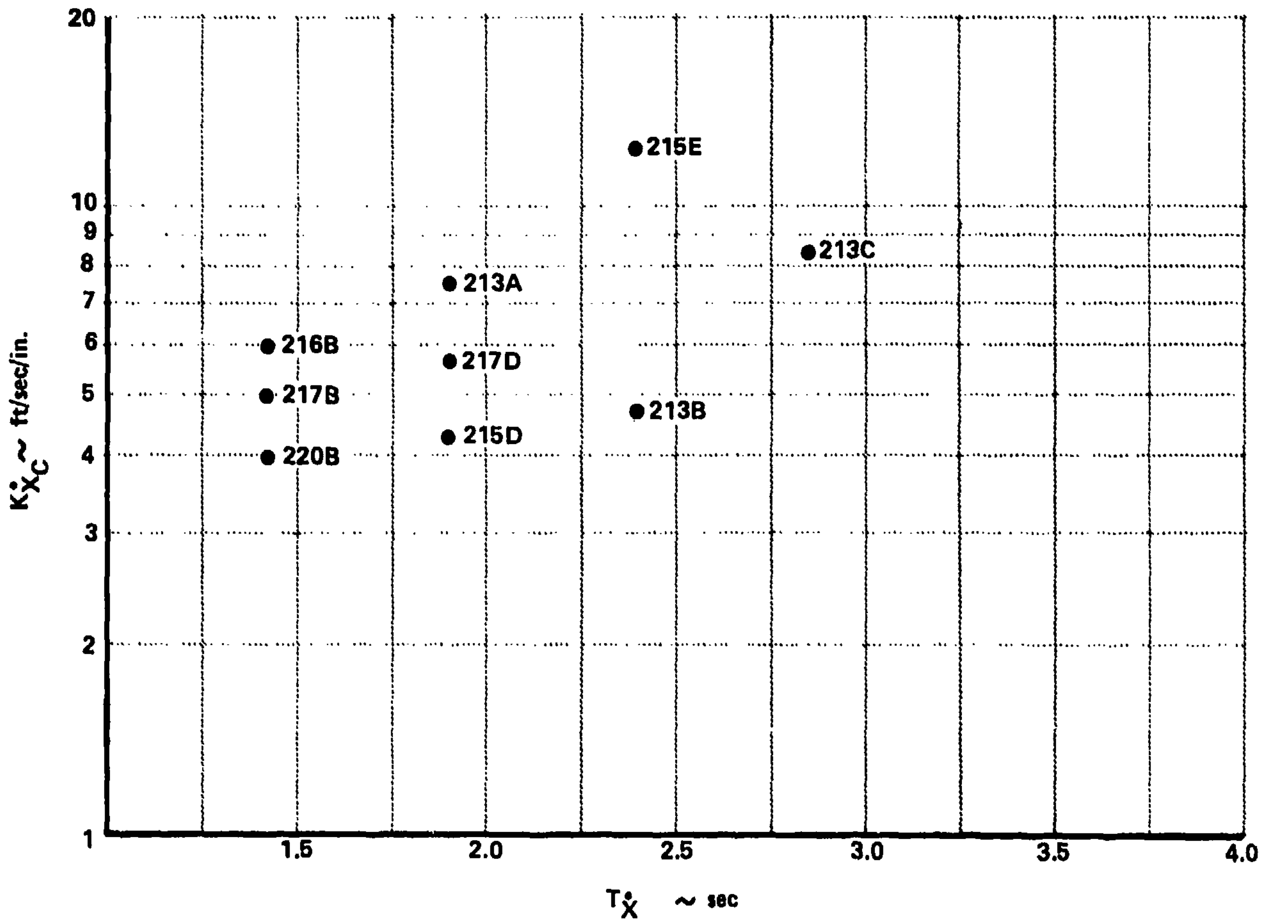


Figure 23b CONFIGURATION IDENTIFIERS FOR TRC SYSTEMS WITH INNER LOOP $\omega_n = 3.0$ r/s

TABLE 6

PILOT COMMENT SUMMARY FOR TRC SYSTEMS

WITH ω_n (INNER LOOP) = 3.0 RAD/SEC

Flt/Config.	Pilot Ratings	Comments
216B	4.5/3	Bit of abruptness.
217B	3/2	Little bit jerky, only thing I didn't like.
220B	6/4	High forces, displacements.
213A	4.5/4	Tendency to drift, attitude response abrupt.
217D	4/3	Problem finding attitude to hold against wind, tendency to dance around, drift.
215D	4/4	Skidded trying to stop, drifts.
215E	4/3	Abruptness, overly sensitive.
213B	7/4	Sluggish, large control forces, displacements.
213C	4.5/4	Overcontrolled corrections when I got into target.

abruptness. Quantitatively, at a given path mode time constant, increasing the inner loop frequency from 2.0 to 3.0 radians/second requires a doubling of the command gain and hence the maximum attitude acceleration to maintain the same velocity sensitivity (ft/sec/in).

In summary, the results of these evaluations indicate that path mode time constant alone is insufficient to characterize satisfactory flying qualities. Because factors such as turbulence sensitivity and attitude abruptness are sensitive not only to the path mode dynamics but also to the relative level of inner loop (attitude) augmentation and outer loop (velocity) augmentation.

4.2.6 Height Dynamics

Preliminary to the investigation of TRC dynamics, several flights were devoted to exploring variations in augmented height dynamics. The intent was first, to establish the variation of flying qualities as a function of vertical modal characteristics and second, to select from these variations a configuration for the investigation of TRC dynamics. The configuration to be selected would exhibit satisfactory and hence unobtrusive flying qualities to permit focussing on the characteristics of the X-Y translational dynamics. A modified evaluation task, emphasizing vertical maneuvering was employed for these evaluations.

As discussed in Section 2.2.3, two types of vertical augmentation were investigated; the first employed feedback of inertial altitude rate while the second added altitude feedback and an integral-proportional command prefilter. The second system was configured to yield first order velocity responses to control commands and thus could be characterized simply by its equivalent vertical damping and command gain. Unlike the first system, however, these configurations provided altitude hold with the throttle at the zero (detent) position.

Unfortunately, the results of these variations are obscured by several factors. First, the evaluations were performed early in the program and the degree of interaction of vertical and translational flying qualities was not fully appreciated. Second, this problem was heightened by the fact

that required characteristics for satisfactory translational dynamics had not yet been established. Finally, the results of several evaluation flights were likely masked by operational difficulties and certain display format deficiencies.

The first evaluations of height dynamics were performed with attitude command augmentation in the pitch and roll axes. Natural frequencies of the attitude dynamics were 2.0 and 2.5 rad/sec with steady gains of 6 deg/inch. The pilot rating results for vertical systems with and without altitude hold are presented in Figure 24a. Flight number identifiers are shown in Figure 24b. The first pilot rating corresponds to combined Y-Z maneuvering while the second rating applies to the vertical landing task only. All the evaluations on Flight 199 were conducted facing the sum which obscured the HUD so that perception of the symbology was extremely difficult. This compromise was a consequence of having to hover into the wind. The remaining evaluations (Flight 195 and 196) employed a preliminary HUD format which did not have centralized symbology. In this format, altitude information was presented to the left of the display as a fixed scale and a moving symbol with a fly-to sense. No assessment of the degree to which the display format influenced ratings is possible but this non-centralized altitude presentation was a major complaint of both the Navy LAMPS and Calspan evaluation pilots. This deficiency was subsequently corrected ofr the remainder of the program. As can be seen by the pilot rating data, no discernable trend is evident either with effective damping or vertical control sensitivity. Furthermore, no clear preference for altitude hold is exhibited, but the commentary indicates an appreciation of the workload relief and decoupling that it provides. Although the sun and the display deficiencies were likely contributing factors to these confused pilot rating trends, likely the inadequacy of attitude command systems for this hovering task was the major problem. According to pilot commentary, the chief difficulty was in maintaining X-Y position while attempting to maneuver vertically.

Consequently, for the remaining height dynamics evaluations, an X-Y TRC control system was inplemented. The natural frequency of the inner loop altitude dynamics was 2.5 rad/sec while the path mode time constant and command gain were 2.4 seconds and 5.0 ft/sec/in., respectively. The selection of these

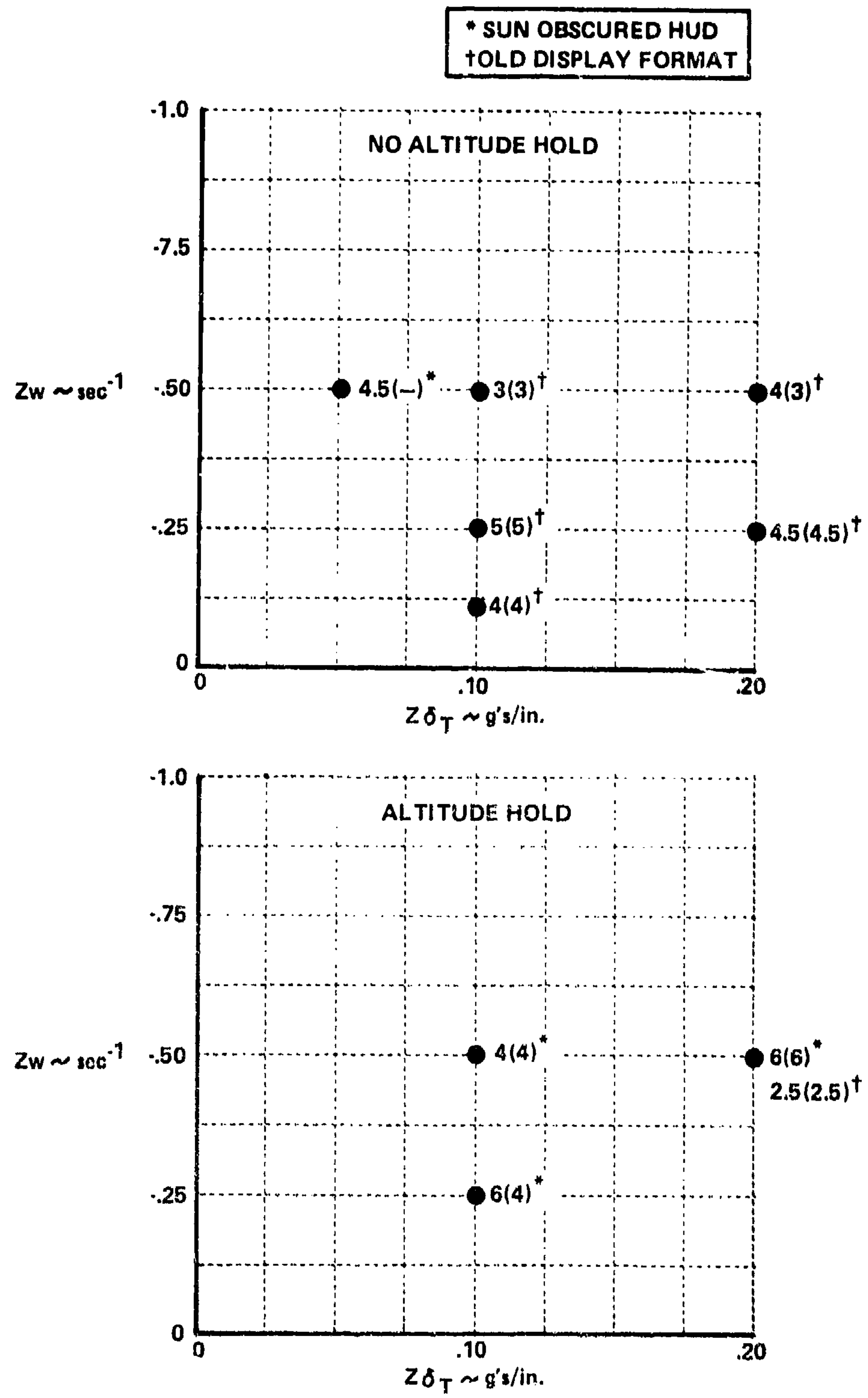
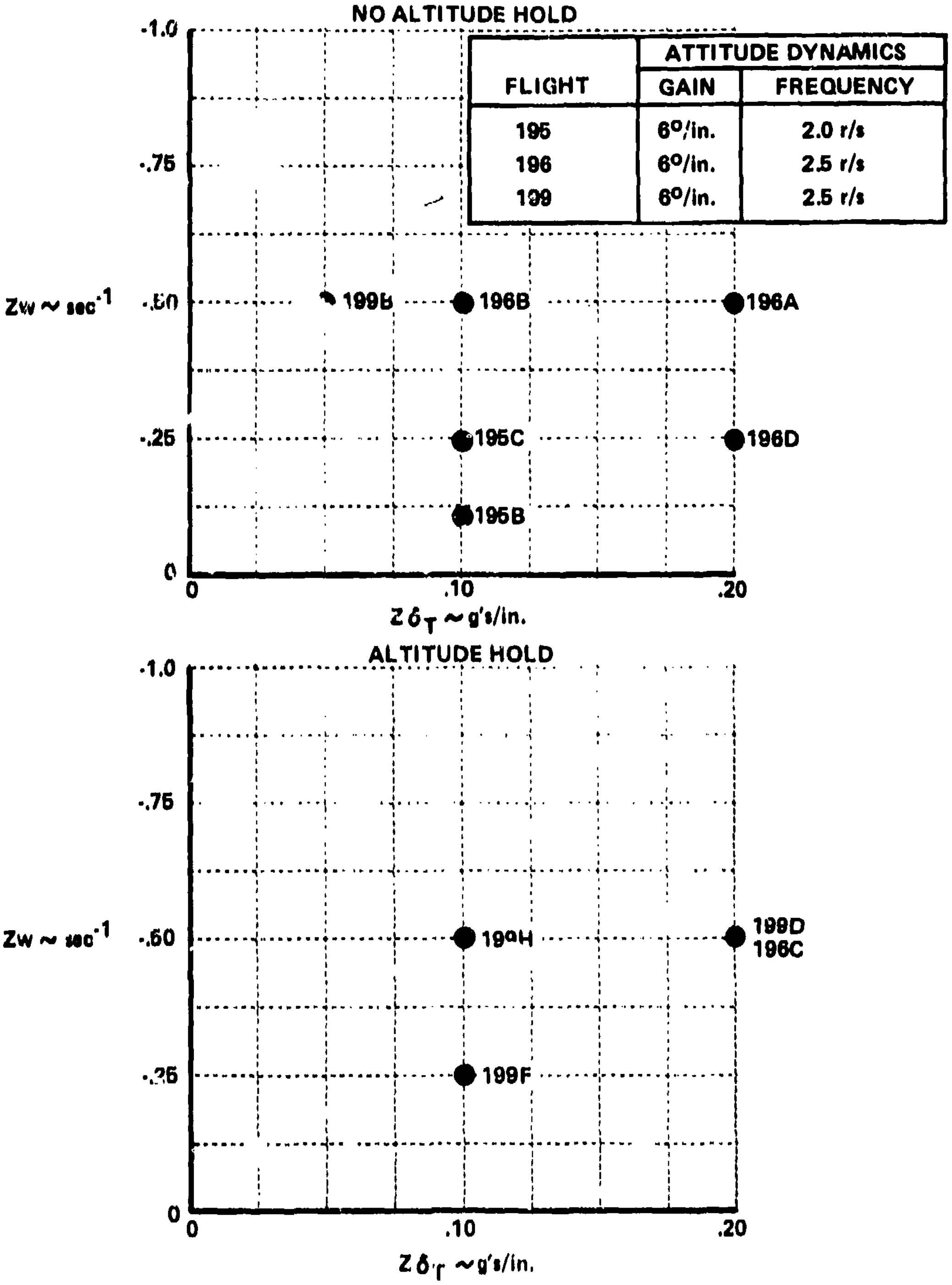


Figure 24a PILOT RATING RESULTS FOR ALTITUDE DYNAMICS VARIATIONS WITH PITCH AND ROLL ATTITUDE STABILIZATION



FLIGHT	ATTITUDE DYNAMICS	
	GAIN	FREQUENCY
195	6°/in.	2.0 r/s
196	6°/in.	2.5 r/s
199	6°/in.	2.5 r/s

Figure 24b CONFIGURATION IDENTIFIERS FOR ATTITUDE DYNAMICS VARIATIONS WITH PITCH AND ROLL ATTITUDE STABILIZATION

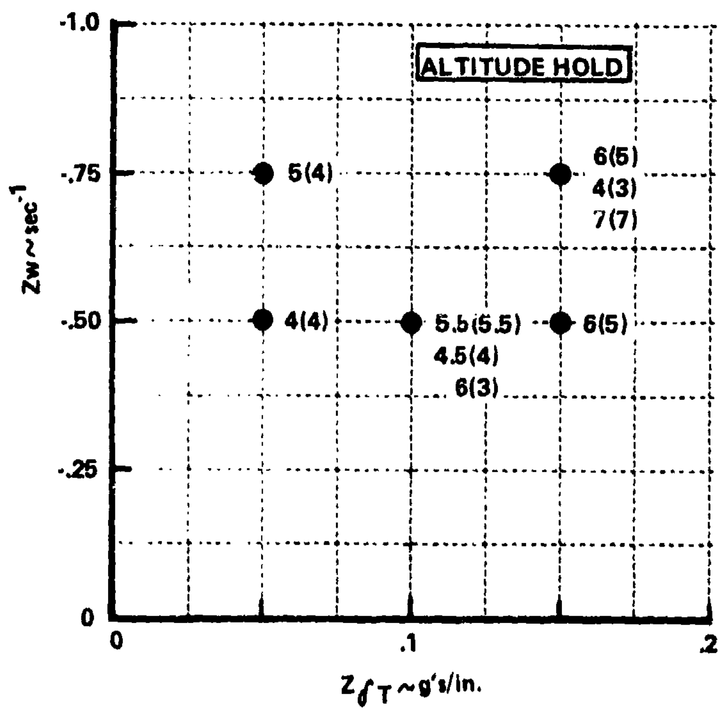


Figure 25a PILOT RATING RESULTS FOR ALTITUDE DYNAMICS VARIATIONS WITH LONG/LAT TRC AUGMENTATION (INNER LOOP ω_n = 2.5 r/s, $K_{\dot{X}_C}$ = 5.0 ft/sec/in., T_X = 2.4 sec)

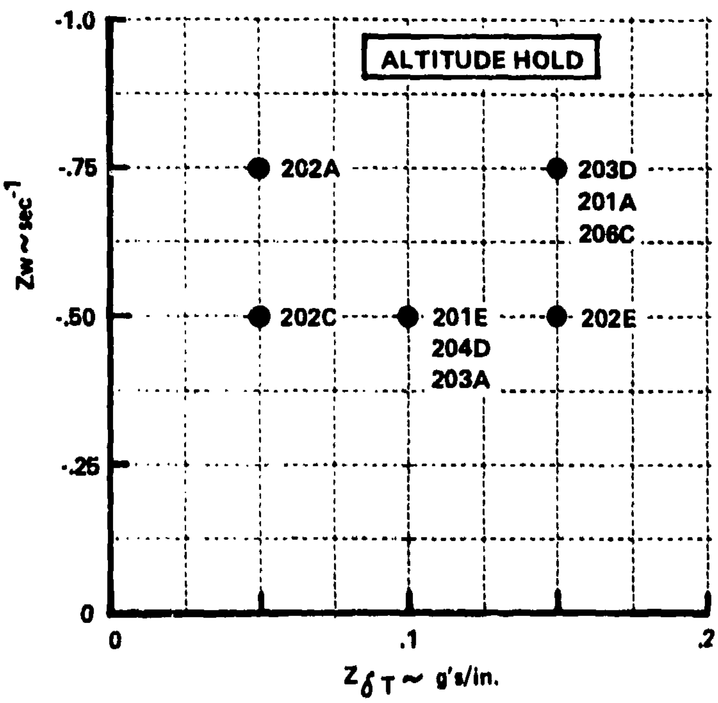


Figure 25b CONFIGURATION IDENTIFIERS FOR ALTITUDE DYNAMICS VARIATIONS WITH LONG/LAT TRC AUGMENTATION (INNER LOOP ω_n = 2.5 r/s, $K_{\dot{X}_C}$ = 5 ft/sec/in., $T_{\dot{X}}$ = 2.4 sec)

TRC dynamics was guided by the results of the simulator investigations of References 5 and 15. Variations in effective vertical damping and vertical control sensitivity for vertical rate command/altitude hold augmentation systems were then evaluated. The pilot rating results are plotted in Figure 25. As in the the previous evaluations, the pilot ratings for Y-Z tracking and the vertical landing task are generally poor and exhibit little functional dependence on the magnitude of damping and control sensitivity. As with the attitude stabilized configurations, pilot commentary pointed to X-Y control difficulties as the major problem. Even in the landing task, the poor ratings are attributable to the difficulty of holding position over the landing pad.

Using pilot commentary as a guide, two vertical configurations were selected as condidate systems for the investigation of TRC dynamics. The first system had vertical damping of -0.5 sec^{-1} and control sensitivity of 0.1 g's per inch of throttle while the second had damping -0.75 sec^{-1} and sensitivity of .15 g's per inch of throttle. As can be seen from the results of the TRC variations (Figure 12), the X-Y dynamic configuration selected for evaluation of height dynamics clearly lies in a region of acceptable but not satisfactory longitudinal flying qualities. This choice led t the poor descrimination of vertical flying qualities rather than any fundamental problem with the vertical dynamics simulated. Unfortunately, time constraints precluded repetition of the vertical augmentation configurations with a TRC system from the identified region of satisfactory flying qualities. However, it is clear from these data that, provided the translational dynamics are satisfactory, Level 1 flying qualities can be obtained with vertical rate command/altitude hold augmentation with effective vertical damping and control sensitivity as low as -0.5 sec^{-1} and 0 1 g's/inch, respectively.

4.3 CONTROL POWER REQUIREMENTS AND CONTROL LIMITING

One goal of the current experiment was to obtain estimates of moment control authority requirements for TRC control implementations. These estimates were obtained first by continuously recording control utilization during evaluation flights conducted with no control limits. Since satisfactory task performance can be obtained with occasional saturation of the available control,

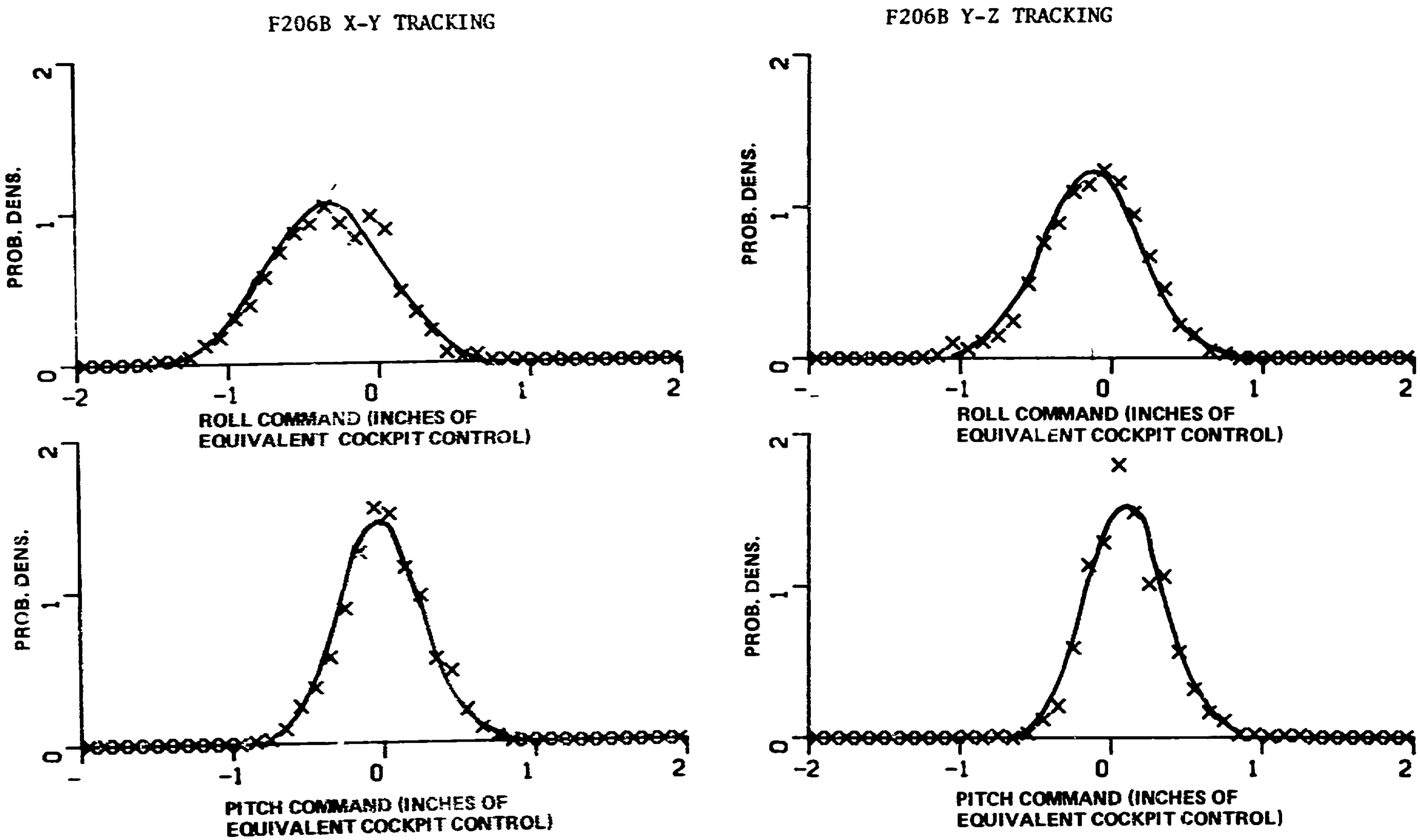


Figure 26 COMPARISON OF MEASURED PROBABILITY DENSITY DISTRIBUTIONS OF CONTROL UTILIZATION WITH GAUSSIAN DISTRIBUTION

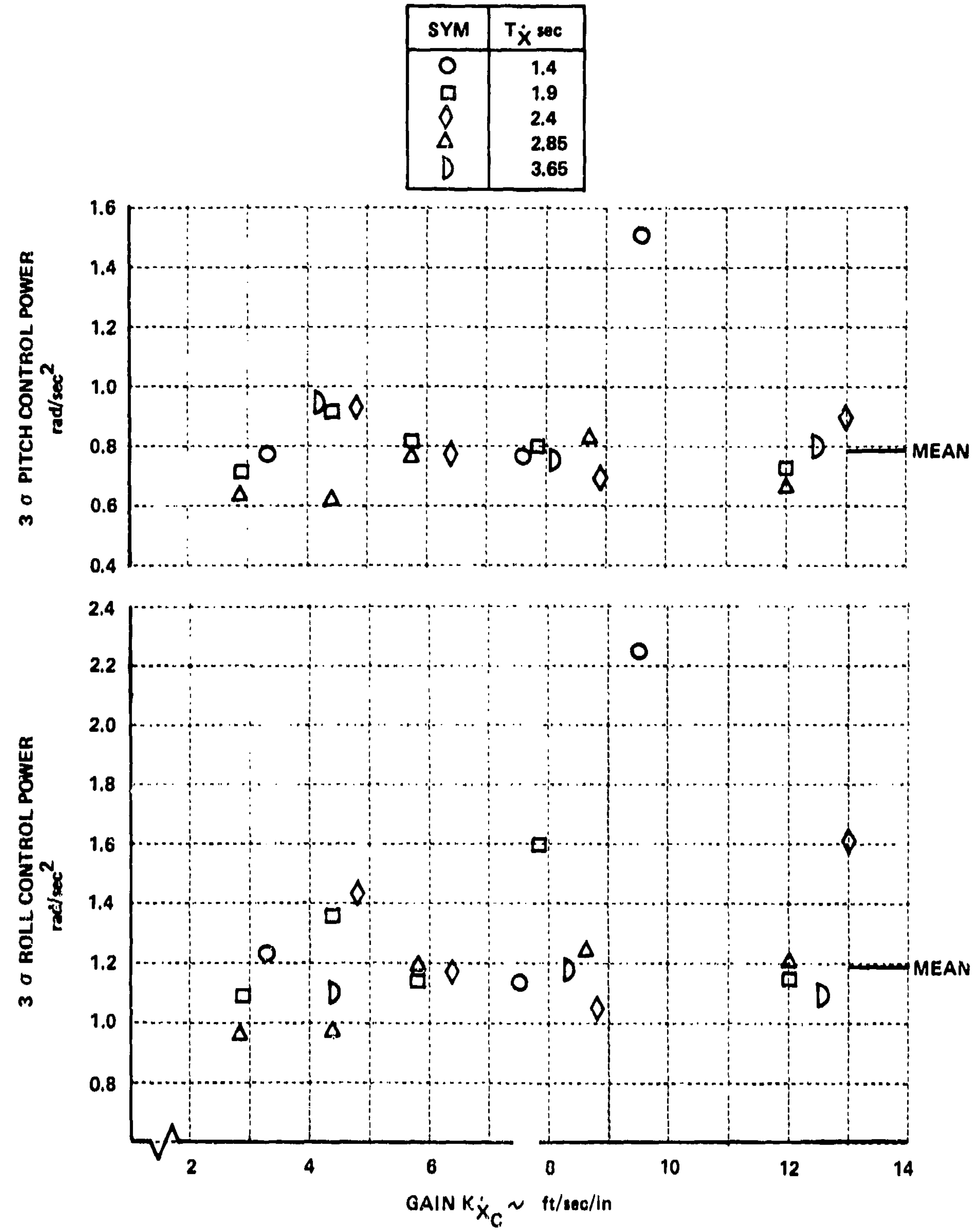


Figure 27 VARIATION OF 3 σ CONTROL POWER VS PATH MODE TIME CONSTANT AND VELOCITY GAIN (PRIMARY MATRIX)

control power estimates obtained from these measures are likely somewhat conservative. Therefore, to obtain an estimate of frequency and magnitude of tolerable control saturation, selected configurations were reflown with control authority limits. Two evaluation flights were devoted to this purpose. The recorded control utilization data was processed to obtain two parameters which are indicators of control required. These parameters are the maximum control command and three times the standard deviation of control command (3σ). The first measure is conservative in that an isolated peak command will determine the magnitude. However, if the control utilization is close to normally distributed, 3σ is perhaps a more representative measure. For a true Gaussian process, less than one percent of the total control demand will exceed $\pm 3\sigma$. Thus, this statistical measure, in effect, will tend to automatically exclude occasional large but not representative control power commands. Samples of probability density plots for control power are compared to exact normal distributions in Figure 26. It is evident that actual control utilization is nearly Gaussian which validates 3σ as a control power measure. For each evaluation, maximum control amplitudes and 3σ moments were separately computed for each subtask (i.e., X-Y tracking, Y-Z tracking, vertical landing) to minimize averaging effects in the estimates of standard deviation. Statistical data summaries are presented in Appendix V.

In order to assess the sensitivity of control power requirements to system dynamics and command gain, 3σ control power was plotted as a function of path mode time constant and velocity sensitivity (Figure 27). Where evaluations were repeated, the worst case data were chosen for these summary plots. Since ground simulator experiments (Reference 15) indicated an inverse relationship between control sophistication and required control power, it was anticipated that these data might reveal a similar trend, that is, reduced control demand with lower path mode time constants.

As can be seen by Figure 27, the data summary plot for the baseline experiment matrix (inner loop ω_n = 2.5), there appears to be no functional relationship between control power required and path mode time constant or command gain (velocity sensitivity). Using average values as representative of the data, roll control power requirements are about 50 percent higher than

pitch. This result is not surprising since pilots are less reluctant to maneuver aggressively laterally than longitudinally.

Since the two pilots participating in this program appeared to be using different control techniques (Section 4.2.3), control power data for the second pilot was analyzed separately. Again, no discernable dependence of control power on dynamics or control gain was evident. The second pilot, however, did use slightly less control in each axis. As with the primary pilot, roll requirements were about 60 percent higher than pitch. Mean and standard deviations of control usage for all path mode time constants and command gains for the two pilots are summarized below.

TABLE 7

CONTROL POWER UTILIZATION FOR BASELINE MATRIX

(inner loop ω_n = 2.5 rad/sec)

		PRIMARY PILOT	SECOND PILOT
Pitch	Mean	0.79 rad/sec^2	0.69 rad/sec^2
	St'd Dev'n	0.17 rad/sec^2	0.13 rad/sec^2
Roll	Mean	1.19 rad/sec^2	1.10 rad/sec^2
	St'd Dev'n	0.27 rad/sec^2	0.19 rad/sec^2

Since changing the frequency of the inner loop attitude dynamics modifies the abruptness of control response, the data for the 2.0 and 3.0 rad/sec inner loop systems was similarly analyzed. As can be seen from Table 8, control utilization in pitch appears to be little changed while in roll there is evidence that control demand increases with inner loop frequency. Possibly this trend is attributable to the fact that lateral maneuvering is more comfortable and when the control system dynamics are sufficiently fast, the pilot will utilize the capability.

TABLE 8

CONTROL POWER UTILIZATION WITH
DIFFERENT INNER LOOP ATTITUDE DYNAMICS (PRIMARY PILOT)

		$\omega_n = 2.0$	$\omega_n = 3.0$
Pitch	Mean	0.72 rad/sec^2	0.82 rad/sec^2
	St'd Dev'n	0.08 rad/sec^2	0.07 rad/sec^2
Roll	Mean	1.13 rad/sec^2	1.49 rad/sec^2
	St'd Dev'n	0.15 rad/sec^2	.47 rad/sec^2

Two flights were devoted to assessing the impact of limited control authority on flying qualities. Because control limits could not be changed in flight, iteration of limits to find the magnitude at which control saturation became significant was impractical. Therefore, recorded control time histories from flights with unlimited authority were used to select limits for flight testing. Since no statistical analyses had been performed at this time, the selection was based on engineering estimates of maximum excursions to approximately determine the 3σ values. It was concluded, based on a sampling of data at a variety of command gains and path mode time constants, that control utilization was approximately the same for all configurations.

For flight 219 target limit values of 0.8 and 1.1 rad/sec^2 in pitch and roll respectively were selected for evaluation. As can be seen from the statistical summary plots, these limits were close to the actual mean control usage for the baseline configuration matrix. Because of an implementation error, the limits actually set were 0.86 and 0.89 rad/sec^2 in pitch and roll, respectively. As a result, examination of control time history records indicated only infrequent limit encounters in pitch while in roll the saturations were frequent and more prolonged to the extent that on one of the four evaluations (219D) control was lost (P.R. = 10) and on 219B, controllability was seriously in question (P.R. = 9). Table 9 summarizes the pilot rating data

TABLE 9. SUMMARY OF PILOT RATING RESULTS FOR CONFIGURATIONS WITH LIMITED AND UNLIMITED CONTROL AUTHORITY

			Pitch lim = None Roll lim = None		Pitch lim = 0.86 rad/sec^2 Roll lim = 0.89 rad/sec^2		Pitch lim = 0.72 rad/sec^2 Roll lim = None	
$K_{\dot{x}_c}$	$T_{\dot{x}_{EQ}}$	ω_n (inner)	Flt. No.	Ratings	Flt. No.	Ratings	Flt. No.	Ratings
5.0	1.5	2.5	209C	3/2	219A	5/4	221A	5/4
9.0	3.0	2.5	217C	5/4	219B	9/6	221B	8/6
			206F	5/5				
12.0	2.0	2.5	209A	5/4	219C	4/3	221C	10/10
6.0	1.5	3.0	206F	4.5/--	219D	10/10	221D	8/5

with and without control limits for the four configurations evaluated on this flight. It was concluded, based on these data, that a roll authority limit of 0.89 rad/sec^2 had penetrated the knee in the pilot rating versus authority relationship to the extent that this level of control power is unacceptable in that lateral flying qualities are seriously degraded and that, on occasion, control is lost.

Since only the onset of pitch authority limit encounters was observed on flight 219, for flight 221 it was decided to assess the effect of a further small reduction in authority to 0.72 rad/sec^2. The roll authority was unlimited to focus on the effects of degraded longitudinal control. As can be seen from the data summary of Table 9, the degradation in the pitch axis flying qualities parallels those of the roll axis for the earlier flight. The cliff-like effect of a small change in control authority (.14 rad/sec^2) is evident in these data in that loss of control was encountered on one configuration and serious control difficulties resulted on two others. In summary, these data indicate that, for satisfactory flying qualities, control authority limits near the 3σ level of demand are marginal. As indicated by the results for the pitch axis, the margin between infrequent limit encounters with little effect on flying qualities and hard saturation leading to loss of control is small.

4.4 ALTERNATE TRC RESPONSE CRITERION

In Section 2.2.1, it is concluded from analyses that equivalent path mode time constant is an inadequate criterion for attitude-type TRC systems first, because it does not reflect the gust sensitivity effects of trading off airspeed and inertial velocity stability and second, because this single parameter does not uniquely specify the dynamics of typical third order TRC systems.

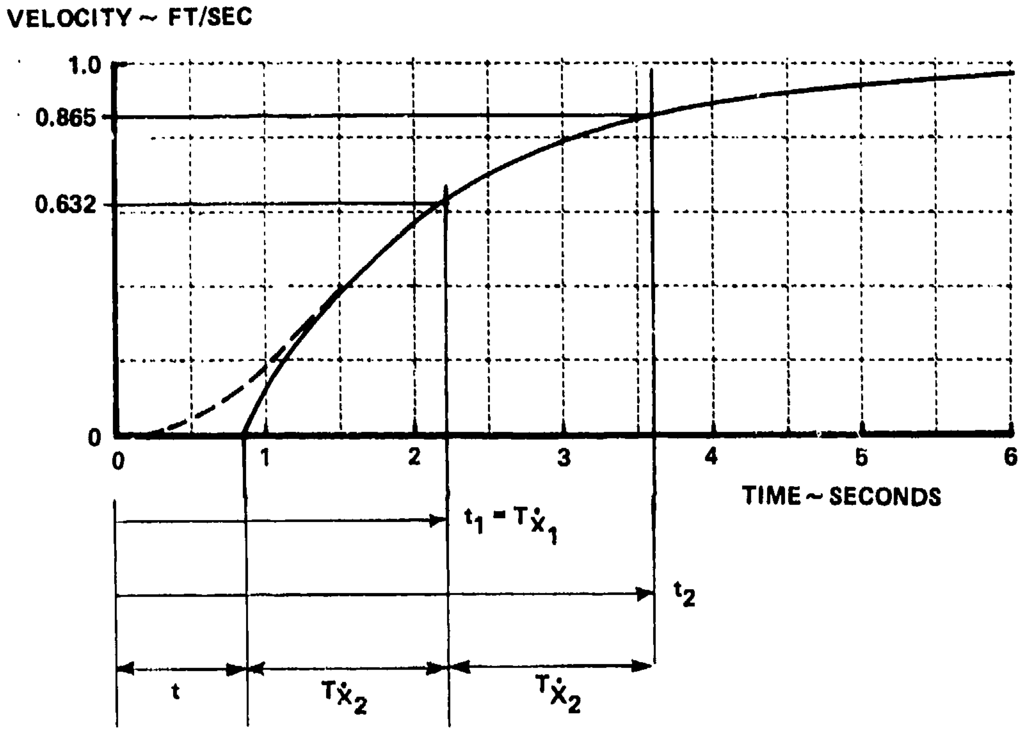
A method for addressing the latter deficiency is to increase the order of the criterion model to better match the salient response characteristics of actual TRC systems. A possible model form which would provide better time and frequency domain matches of TRC velocity responses is:

$$\frac{\dot{x}}{\varepsilon_{ES}} = \frac{K_{\dot{x}_e} e^{-\tau s}}{T_{\dot{x}_2} s+1}$$

Many methods could be used to estimate the parameters of this model either from flight-generated data or an exact analytical model. For the analyses to follow, the procedure employed was to calculate the coefficients $\left(T_{\dot{x}_2}, \tau\right)$ which provide a "best" fit time domain match to the step response of the identified transfer function models. The subscript 2 notation is introduced to differentiate between the time constant of a two-parameter equivalent system model and the time constant of a one-parameter model. As diagrammed in Figure 28, $T_{\dot{x}_2}$ was calculated as the difference between t_2 and t_1, the times to 86.5 and 63.2 percent of steady response, respectively and τ as the difference of t_1 and $T_{\dot{x}_2}$. It is observed that the time constant of the one-parameter model, $T_{\dot{x}_1}$, is the sum of the time delay and first order time constant of the two-parameter model. That is:

$$T_{\dot{x}_1} = \tau + T_{\dot{x}_2}$$

Figure 29 illustrates the variation of these parameters as functions of the variables of this experiment, frequency of the inner loop attitude dynamics and path mode time constant. The equivalent time delay τ correlates approximately with the frequency of the inner loop attitude dynamics. The results of this experiment indicate that the region of Level 1 flying qualities (PR $\leqslant$ 3.5) are approximately bounded by inner loop frequencies of 2.0 and 3.0 radians/sec and by a maximum path mode time constant, $T_{\dot{x}_1}$, of about 2.3 seconds. Because of the functional relationship between $T_{\dot{x}_2}$, τ and $T_{\dot{x}_1}$, ω_n (inner loop), these boundaries could also be expressed in terms of these alternate parameters as indicated by the dashed lines. The upper bounds on $T_{\dot{x}_2}$ and τ are flying



EXACT: $\dot{x}/\delta_{ES} = \dfrac{3.544}{(S+0.7)(S^2+2(0.7)(2.25)S+2.25^2)}$

APPROX: $\dot{x}/\delta_{ES} = \dfrac{e^{-0.827S}}{(1+1.38S)}$

Figure 26 EXAMPLE OF TWO PARAMETER EQUIVALENT SYSTEM CALCULATION

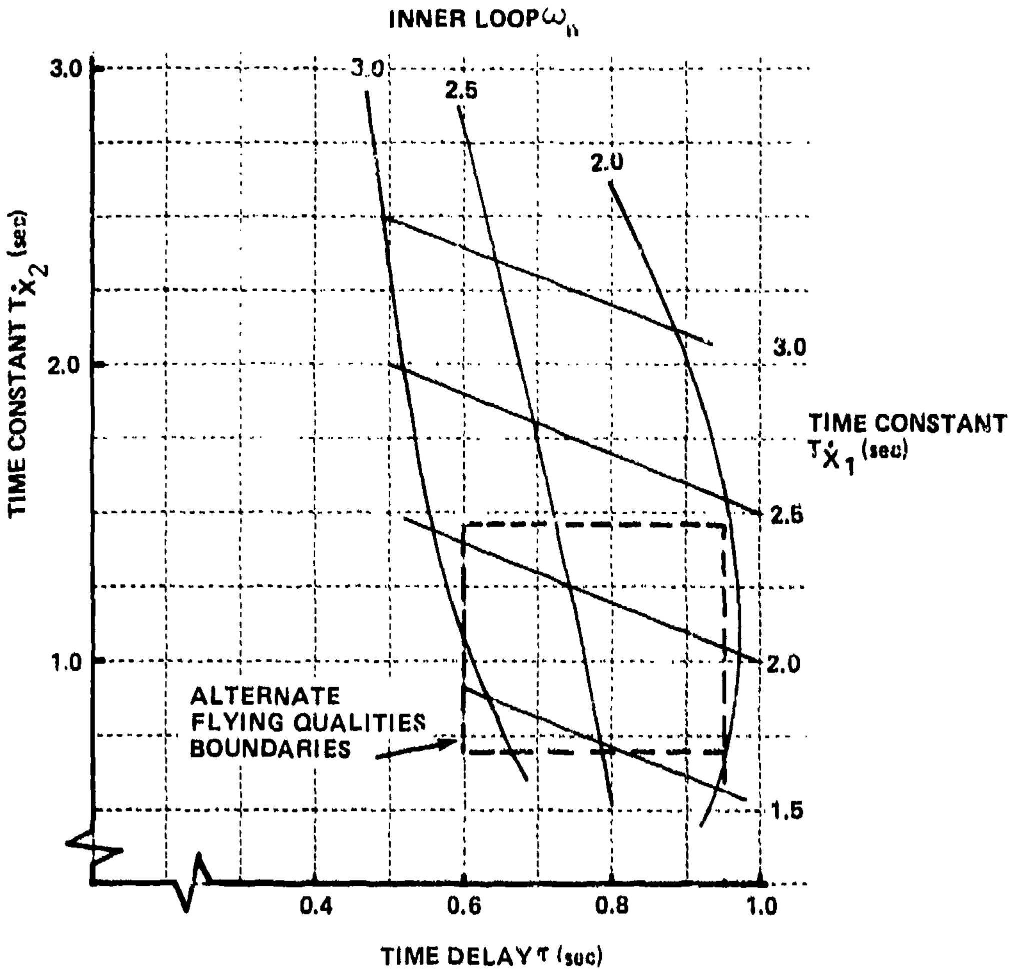


Figure 29 SPECIFICATION OF FLYING QUALITIES WITH RESPECT TO TWO-PARAMETER TRC CRITERIA MODEL

qualities limits associated with excessive phase lag in the open loop aircraft velocity response. The lower bound on τ at about 0.6 seconds reflects a ride qualities limit associated with excessive abruptness in the secondary attitude responses. This limit, therefore, is a consequence of using vehicle rotation for generation of horizontal forces and would not exist for direct force translational rate control implementations.

This analysis indicates that a modified lower order model comprised of first order lag and cascaded pure time delay has promise as criterion for attitude-type TRC systems. It is noted, however, that this augmented model is intended only to provide improved modeling of control response characteristics and does not address the other deficiency noted in the analysis of Section 2.2.1, that is, turbulence or gust sensitivity.

Section 5
CONCLUSIONS

The flight experiment described in this report employed the X-22A variable stability V/STOL aircraft to investigate criteria for inertial translational rate control systems. The simulation scenario was intended to be representative of small ship visual landings under high sea state and wind-over-deck conditions. Synthetic ship wake turbulence and a HUD-generated discrete tracking task were employed as analogues of the actual flight environment and tasks. In this context the following conclusions are drawn:

1. The HUD discrete tracking task, employed in this experiment, provided a repeatable, paced evaluation task suitable for discrimination of hover flying qualities characteristics.

2. The flying qualities results for height augmentation system variations were masked somewhat by the choice of X-Y TRC dynamics. However, pilot commentary indicated a clear preference for vertical rate command with altitude hold because of the decoupling of vertical from horizontal degrees of freedom. Effective vertical damping as low as -.5 to -.75 sec^{-1} and control sensitivities of .1 to .15 g's per inch provided satisfactory flying qualities.

3. With the height dynamics augmented as described above, satisfactory flying qualities (PR $\leq$ 3.5) can be achieved with attitude-type TRC systems provided the dynamics are within the limits defined in this experiment.

4. With the same vertical augmentation, pitch and roll attitude command systems will provide acceptable but not satisfactory flying qualities (3.5 < PR $\leq$ 6.5).

5. Pilot commentary indicated that control of longitudinal position was clearly more difficult than lateral position because of drifting caused by winds and turbulence. The relative ease of lateral control may have been a consequence of selecting the hover heading to provide zero sideslip in headwinds.

6. Pitch and roll control power utilization appears to be invariant with closed-loop dynamics although some tendency for control power requirements to increase with the frequency of the inner loop attitude dynamics was observed. Limiting the control available to the 3σ level of control demand can seriously degrade flying qualities and may lead to loss of control.

7. The two evaluation pilots participating in this experiment appeared to use different control techniques. The comments of the primary pilot indicate a tendency to close an inner attitude loop when flying the tracking task. The comments of the second pilot, on the other hand, indicate that he tended to control the outer velocity loop directly. Although differences in pilot rating results between the two pilots were observed, these differences are attributed more to the low level of experience and learning effects with the second pilot.

Section 6
RECOMMENDATIONS

On the basis of the results of this experiment, the following recommendations for future work are pertinent for further investigations of VTOL shipboard landings:

1. The effect of trading off aerodynamic and inertial speed stability on control and turbulence response should be explored systematically. The current experiment was conducted with constant M_u.

2. Because of the difficulty of longitudinal position control, incorporation of position hold in the TRC control mechanizations should be considered.

3. The feasibility of reducing longitudinal gust response using collective elevon (X-force) control should be investigated.

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Appendix I
RUN LOG

This appendix contains the log of configurations evaluated in this experiment arranged in chronological order. Since pertinent raw experimental data is identified in the body of the report by a flight and configuration number, location of specific configurations in the log is facilitated using this identifier. The pilots are designated by:

P - Primary pilot
S - Second pilot
N - Navy LAMPS pilot

The parameters for longitudinal, lateral and vertical dynamics presented in this appendix are nominal or design values.

		Long/Lateral Dynamics			Vertical Dynamics			Pilot Ratings		Pilot
Flt.	Config.	$K_{\dot{x}_c}$	$T_{\dot{x}_{EC}}$	Inner Loop ω_n	Z_{δ_T}	Z_w	Alt. Stab.	Man.	Lndg.	
195	B	att.sys.ω_n=2.0r/s		6°/in	X-22A		No	4	4	P
	C	"	"	"	.1	.25	No	5	5	"
196	A	att.sys.ω_n=2.5r/s		6°/in	.2	.5	No	4	3	"
	B	"	"	"	.1	.5	No	3	3	"
	C	"	"	"	.2	.5	Yes	2.5	2.5	"
	D	"	"	"	.2	.25	No	4.5	4.5	"
199	B	att.sys.ω_n=2.5r/s		6°/in	.05	.5	No	4.5		"
	D	"	"	"	.2	.5	Yes	6	6	"
	F	"	"	"	.1	.25	Yes	6	4	"
	H	"	"	"	.1	.5	Yes	4	4	"
201	A	5.0	2.5	2.5	.15	.75	Yes	4	3	"
	B	6.0	3.0	2.5	.10	.5	Yes	3	2	"
	C	5.0	2.5	2.5	.10	.25	No	6	6	"
	D	3.0	3.0	2.5	.1	.5	Yes	7	6	"
	F	3.0	2.0	2.5	.1	.5	Yes	6	4	"
202	A	5.0	2.5	2.5	.05	.75	Yes	5	4	"
	B	5.0	5.0	2.5	.10	.50	Yes	7	5	"
	C	5.0	2.5	2.5	.05	.50	Yes	4	4	"
	D	4.5	2.0	2.5	.10	.50	Yes	2	2	"
	E	5.0	2.5	2.5	.15	.50	Yes	6	5	"
	F	4.5	3.0	2.5	.10	.50	Yes	5	4	"

		Long/Lateral Dynamics			Vertical Dynamics			Pilot Ratings		Pilot
Flt.	Config.	K_{x_c}	$T_{x_{E_c}}$	Inner Loop ω_n	Z_{δ_T}	Z_w	Alt. Stab.	Man.	Lndg.	
203	A	5.0	2.5	2.5	.1	.5	Yes	6	3	P
	B	4.5	4.0	2.5	.1	.5	Yes	8	8	"
	C	9.0	3.0	2.5	.1	.5	Yes	5	4	"
	D	5.0	2.5	2.5	.15	.5	Yes	6	5	"
	E	9.0	4.0	2.5	.10	.5	Yes	4.5	4	"
204	A	4.5	2.0	2.5	.1	.5	Yes	4	3	"
	B	9.0	3.0	2.5	.1	.5	Yes	5	4	"
	C	6.0	3.0	2.5	.1	.5	Yes	6	5	"
	D	5.0	2.5	2.5	.1	.5	Yes	4.5	4	"
205	A	4.5	2.0	2.5	.15	.75	Yes	2	2	"
	B	4.5	4.0	2.5	.15	.75	Yes	7	6	"
206	A	6.0	3.0	2.5	.15	.75	Yes	3	2	"
	B	6.0	2.0	2.5	.15	.75	Yes	4	2	"
	D	9.0	4.0	2.5	.15	.75	Yes	6	6	"
	C	5.0	2.5	2.5	.15	.75	Yes	7	7	"
	F	9.0	3.0	2.5	.15	.75	Yes	5	5	"
207	A	13.0	4.0	2.5	.15	.75	Yes	4.5	3	"
	B	5.0	2.25	2.5	.15	.75	Yes	3.5	2	"
	C	8.0	2.0	2.5	.15	.75	Yes	3.5	2	"
	D	8.0	3.5	2.5	.15	.75	Yes	5.5	4	"
	E	6.5	2.5	2.5	.15	.75	Yes	5.5	4	"

Flt.	Config.	Long/Lateral Dynamics			Vertical Dynamics			Pilot Ratings		Pilot
		$K_{\dot{x}_c}$	$T_{\dot{x}_{EQ}}$	Inner Loop ω_n	Z_{δ_T}	Z_w	Alt. Stab.	Man.	Lndg.	
208	A	5.5	2.75	2.5	.15	.75	Yes	6	4	P
	B	6.0	2.0	2.5	.15	.75	Yes	4	3	"
	C	9.0	2.5	2.5	.15	.75	Yes	4	--	"
209	A	12.0	2.0	2.5	.15	.75	Yes	3	4	"
	B	6.0	3.0	2.5	.15	.75	Yes	7	5	"
	C	5.0	1.5	2.5	.15	.75	Yes	3	2	"
	E	12.0	3.0	2.5	.15	.75	Yes	6	5.5	"
211	A	13.0	2.5	2.5	.15	.75	Yes	4.5	3	"
	B	3.5	1.5	2.5	.15	.75	Yes	4.5	3	"
	C	10.0	1.5	2.5	.15	.75	Yes	4	--	"
212	D*	6.0	3.0	2.5	.15	.75	Yes	3		"
	E*	att.sys.2.5 r/s		6^0/in	.15	.75	Yes	4.5		"
	F*	6.0	2.0	2.5	.15	.75	Yes	4		"
	G*	9.0	3.0	2.5	.15	.75	Yes	5		"
213	A	8.0	2.0	3.0	.15	.75	Yes	4.5	4	"
	B	5.0	2.5	3.0	.15	.75	Yes	7	4	"
	C	9.0	3.0	3.0	.15	.75	Yes	4.5	4	"
	E*	13.0	2.5	2.5	.15	.75	Yes	3		"
214	A*	5.0	1.5	2.5	.15	.75	Yes	7		"
	B*	13.0	4.0	2.5	.15	.75	Yes	5		"
	C*	12.0	2.0	2.5	.15	.75	Yes	4		"
	H*	8.0	1.5	2.5	.15	.75	Yes	2		"

*Ground referenced task

Flt.	Config.	Long/Lateral Dynamics $\dot{K}_{x_c}$	$\dot{T}_{x_{EQ}}$	Inner Loop ω_n	Vertical Dynamics z_{δ_T}	Z_w	Alt. Stab.	Pilot Ratings Man.	Lndg.	Pilot
215	D	4.5	2.0	3.0	.15	.75	Yes	4	4	P
	E	13.0	2.5	3.0	.15	.75	Yes	4	3	"
216	A	6.0	3.0	2.0	.15	.75	Yes	8	8	"
	B	6.0	1.5	3.0	.15	.75	Yes	4.5		"
	D	6.0	1.5	2.0	.15	.75	Yes	5	4	"
217	A	6.0	2.0	2.0	.15	.75	Yes	5	4	"
	B	6.0	1.5	3.0	.15	.75	Yes	3	2	"
	C	9.0	3.0	2.5	.15	.75	Yes	5	4	"
	D	6.0	2.0	3.0	.15	.75	Yes	4	3	"
218	E	8.0	1.5	2.5	.15	.75	Yes	4	3	"
	F	6.0	2.0	2.5	.15	.75	Yes	4.5	2.0	"
	G	5.0	1.5	2.5	.15	.75	Yes	7	3	"
	H	6.0	1.5	2.0	.15	.75	Yes	5	5	"
219	A	5.0	1.5	2.5	.15	.75	Yes	5	4	"
	B	9.0	3.0	2.5	.15	.75	Yes	9	6	"
	C	12.0	2.0	2.5	.15	.75	Yes	4	3	"
	D	6.0	1.5	3.0	.15	.75	Yes	10	10	"
220	A	9.0	1.5	2.0	.15	.75	Yes	4.5	4	"
	B	4.0	1.5	3.0	.15	.75	Yes	6	4	"
	C	6.0	1.5	2.0	.15	.75	Yes	3	3	"
	D	9.0	2.0	2.0	.15	.75	Yes	5.5	4	"

		Long/Lateral Dynamics			Vertical Dynamics			Pilot Ratings		Pilot
Flt.	Config.	$K_{\dot{x}_c}$	$T_{\dot{x}_{E}}$	Inner Loop ω_n	Z_{δ_T}	Z_w	Alt. Stab.	Man.	Lndg.	
221	A	5.0	1.5	2.5	.15	.75	Yes	5	4	P
	B	9.0	3.0	2.5	.15	.75	Yes	8	6	"
	C	12.0	2.0	2.5	.15	.75	Yes	10	10	"
	D	6.0	1.5	3.0	.15	.75	Yes	8	5	"
222	A	5.0	2.5	2.5	.15	.75	Yes	5	5	N
	B	5.0	1.5	2.5	.15	.75	Yes	6	--	"
	C	9.0	2.5	2.5	.15	.75	Yes	7	--	"
223	A	6.0	1.5	2.5	.15	.75	Yes	2	--	"
	B	8.0	2.0	2.5	.15	.75	Yes	5	--	"
	C	4.5	2.0	2.5	.15	.75	Yes	7	--	"
224	A	4.5	2.0	2.5	.15	.75	Yes	6	6	S
	B	6.0	1.5	2.5	.15	.75	Yes	4	3	"
	C	6.5	2.5	2.5	.15	.75	Yes	7	7	"
225	A	6.0	2.0	2.5	.15	.75	Yes	3	3	"
	B	3.5	1.5	2.5	.15	.75	Yes	4	4	"
	D	8.0	1.5	2.5	.15	.75	Yes	4	4	"
	C	9.0	2.5	2.5	.15	.75	Yes	5	4	"
226	A	2.5	1.5	2.5	.15	.75	Yes	7	7	"
	B	12.0	2.0	2.5	.15	.75	Yes	5	5	"
	C	4.5	2.0	2.5	.15	.75	Yes	4	4	"
	D	13.0	4.0	2.5	.15	.75	Yes	7	7	"

		Long/Lateral Dynamics			Vertical Dynamics			Pilot Ratings		Pilot
Flt.	Config.	$K_{\dot{x}_c}$	$T_{\dot{x}_{EQ}}$	Inner Loop ω_n	Z_{δ_T}	Z_w	Alt. Stab.	Man.	Lndg.	
227	A	6.0	1.5	2.5	.15	.75	Yes	3	3	S
	B	8.0	2.0	2.5	.15	.75	Yes	5	5	"
	C	4.5	1.5	2.5	.15	.75	Yes	4	4	"
	D	6.0	1.5	2.0	.15	.75	Yes	6	5	"
	E	6.0	1.5	3.0	.15	.75	Yes	6	6	"

Appendix II
PILOT COMMENT SUMMARY

Summaries of all the pilot comments for the configurations evaluated in this experiment are presented in this appendix. These summaries were prepared from transcriptions of the tape-recorded comments made by the pilot at the conclusion of each evaluation. The summaries correspond directly to the major headings on the Pilot Comment Card presented in Section 3.

The comments as presented here are either direct quotations or minor paraphrasings of the actual transcriptions. In cases where it might not be clear from the recorded comments exactly what the pilot meant, explanatory editorial phrases are included in parentheses for clarity.

The table at the top of each page of comments gives the control system configuration implemented for the evaluation. As discussed in Section 3, the pilot assigned two pilot ratings for each evaluation configuration, one for the X-Y-Z tracking task, and one for the simulated vertical landing. These are summarized in the table as: X-Y-Z tracking/vertical landing. The TRC dynamics are characterized by the steady state velocity gain, nominal path mode time constant and natural frequency of the inner loop attitude dynamics as: gain/path mode/inner loop frequency. Similarly, height dynamics are presented as: vertical control sensitivity (g's/inch)/vertical damping. The postscript A designates an altitude hold configuration. Unless otherwise noted under GENERAL, the evaluations were performed by the primary pilot.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
Att.Command 2 r/s,6 deg/in	.1/.12	4/4	195B	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Predictability quite good. Could initiate and stop lateral translation. Had trouble in pitch, telling what attitude needed for hover.

- **Attitude:** Predictable, both pitch and roll.

- **Height:** Fairly easy. Didn't have to pay attention to it.

- Precision vs. Gross Maneuvering: Gross acquisition quite precitable. Hover, had trim difficulty both in X-Y, Y-Z and landing task. No undesirable motion.

- Forces, Displacements: Forces good, maybe bit on high side. Displacements comfortable. Control harmony felt pretty good.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Controllable, adequate performance with moderate pilot workload. Not satisfactory without improvement. Primary problem was ability to set up a pitch attitude. Minor but annoying deficiency.

- Landing: Same comments. Problem was longitudinal positioning.

TURBULENCE EFFECTS: Noticeable and it did increase the workload.

GENERAL: Primary objectionable feature was finding the pitch attitude for trim.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
Att.Command 2 r/s,6deg/in	.1/.25	5/5	195C	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation: Predictable getting started. Bit of trouble stopping it (in X) because of finding pitch attitude for hover.

- Attitude: Response predictability felt quite good both in terms of initiating and stopping. Very large pitch attitude changes required to get things going.

- Height: Seemed to be spending more time fiddling with it. May have been extenuating circumstances (fuel state, engage altitude). However, predictability seemed to be O.K..

- Precision vs. Gross Maneuvering: Gross acquisition pretty good. Hover was the problem. No undesirable motions. Control forces perhaps on the high side. Initial versus final reponse O.K..

- Forces, Displacements: Harmony O.K..

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Low fuel, didn't do all tracking tasks. Had trouble with longitudinal positioning of the aircraft. Adequate performance with tolerable workload.

- Landing: Height control predictable. No trouble with landing task. In landing task X-positioning was the problem. Spent most of time with X-control.

TURBULENCE EFFECTS: Moderate, definitely increases the workload.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
Att.Command 2.5 r/s,6 deg/in	.2/.5	4/3	196A	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation: Predictable. May have been a bit of lag in terms of getting a translation going and stopping it but not bad at all.

- Attitude: Real good in pitch and roll. Lot of trouble figuring out pitch attitude for hover. Predictable in terms of making a change.

- Height: Pretty good. Could stabilize it where I wanted to. Corrections predictable.

- Precision vs. Gross Maneuvering: Not much difference except for squaring away longitudinal position.

- Forces, Displacements: Comfortable, pitch roll harmony felt good.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Y-Z task fairly easy. Only trouble was zeroing the X-error. Airplane predictable in attitude and in lateral translations.

- Landing: Adequate performance, satisfactory without improvement.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
Att.Command 2.5 r/s,6 deg/in	.1/.5	3/3	196B	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation: Fairly good except for little bit of lag.

- Attitude: Predictability good in pitch and roll.

- Height: Quite easy, looked like it wanted to hold altitude. Had trouble finding throttle position for zero climb rate. Tended to have bit of drift.

- Precision vs. Gross Maneuvering: Hovering easy because altitude was holding, gave more time to spend on longitudinal positioning.

- Forces, Displacements: Comfortable, harmony felt good.

- Special Control Techniques: No special techniques. Just square away throttle to stabilize height and then you could spend all your time on X-Y.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Tracking in Y-Z quite easy.

- Landing: Equally easy, workload minimal.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
Att.Command 2.5 r/s,6 deg/in	.2/.5/A	2.5/2.5	196C	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation: Quite good, maybe a little lag in translational motions.

- Attitude: Very predictable.

- Height: This time, things were more stable, less of a tendency to get into a drift.

- Precision vs. Gross Maneuvering: Could set up a closure rate predictably. Could hover more easily with this configuration than the last one. Gross acquisition and hover quite predictable.

- Forces, Displacements: Both felt good, harmony good.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Y-Z tracking pretty good, landing task equally so.

- Landing: Just set up what I wanted and went straight down.

TURBULENCE EFFECTS: Relatively small, less than last configuration.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
Att.Command 2.5 r/s,6 deg/in	.2/.25	4.5/4.5	196D	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation: Good but had to spend more time with it because height control was degraded, less predictable than last time.

- Attitude: Predictable.

- Height: Had to spend more time trying to get height stabilized. More difficulty setting up a rate.

- Precision vs. Gross Maneuvering: Not a whole lot of difference.

- Forces, Displacements: Comfortable, pitch roll harmony felt good.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Y-Z and landing task about equivalent, moderate workload because of slightly degraded height control.

- Landing: Adequate performance required considerable pilot compensation, particularly in height control.

TURBULENCE EFFECTS: Much greater effect with this one than the previous configuration.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
Att.Command 2.5 r/s,6 deg/in	.05/.5	4.5/4.5	199B	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation:

- Attitude: Attitude control fairly abrupt although predictable.

- Height: Control quite easy, clue is to have good sense for the detent which is a little bit difficult.

- Precision vs. Gross Maneuvering:

- Forces, Displacements:

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Problems in X-Y because of difficulty seeing HUD (sunlight) Controllable, adequate performance with tolerable pilot workload.

- Landing:

TURBULENCE EFFECTS:

GENERAL: Trouble seeing HUD in bright sunlight.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
Att.Command 2.5 r/s,6 deg/in	.2/.5/A	6/6	199D	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- Translation: Difficulty seeing HUD (sunlight) so problems in tracking X-Y. React to errors later than I liked. However, predictable in X-Y.

- Attitude:

- Height: Altitude control fairly good.

- Precision vs. Gross Maneuvering:

- Forces, Displacements:

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Adequate performance with tolerable workload, extensive compensation in X-Y.

- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
Att.Command 2.5 r/s,6 deg/in	.1/.25/A	6/4	199F	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Tendency to drift off on X.

- **Attitude:** Predictable but abrupt.

- **Height:** Fairly predictable — attitude corrections tended to set up altitude errors — had to pay more attention to keeping altitude zeroed out.

- **Precision vs. Gross Maneuvering:**
  More trouble with gross acquisition than with hover.

- **Forces, Displacements:** No control force problems.

- **Special Control Techniques:**

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Tracking more difficult than landing — could get adequate performance with tolerable workload — extensive compensation.

- Landing: Adequate performance attainable with tolerable pilot workload — desired performance required moderate pilot compensation.

TURBULENCE EFFECTS:

GENERAL: Difficult to see HUD (sun glare).

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
Att.Command 2.5 r/s,6 deg/in	.1/.5/A	4/4	199H	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Holding X-Y easier than previous ones — predictable.
- **Attitude:**
- **Height:** Predictable — could set up desired rate and stop where I wanted — no tendency to drift off.
- **Precision vs. Gross Maneuvering:**
- **Forces, Displacements:**
- **Special Control Techniques:**

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Desired performance, moderate workload — still has tendency to drift in X — may be associated with glare on HUD — hard to see error when it arises.
- Landing: Adequate performance, tolerable workload — not satisfactory without improvement — desired performance required moderate compensation.

TURBULENCE EFFECTS:

GENERAL: Problems seeing HUD because of sun glare.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.15/.75/A	4/3	201A	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Predictability fairly good — tendency to drift out of position bit more than would like — could acquire and stop in the box O.K., then would drift.

- **Attitude:** Predictability pretty good — inputs produced some attitude oscillations.

- **Height:** Quite easy — held altitude while maneuvering in X-Y — could command rate O.K., stopping not quite as predictable as would like.

- **Precision vs. Gross Maneuvering:** Gross acquisition easiest — in hover tended to move off the spot every so often.

- **Forces, Displacements:** Didn't notice.

- **Special Control Techniques:** None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Controllable, adequate performance attainable — not satisfactory without improvement — minor but annoying deficiencies.

- Landing: Satisfactory without improvement — minimal compensation for desired performance.

TURBULENCE EFFECTS: Not very prominent.

GENERAL: Good features, predictable all round — objectionable features, slight unpredictability in height and tendency to drift out of position.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/3/2.5	.1/.5/A	3/2	201B	

RESPONSE TO CONTROL:

- Translation: Predictability good both in establishing a rate and making small corrections.

- Attitude: Predictability quite good – little bit of abruptness at end.

- Height: Easier than last time.

- Precision vs. Gross Maneuvering: Gross acquisition quite easy to establish – this time had little less trouble hovering.

- Forces, Displacements: no special notice.

- Special Control Techniques: No particular control technique – had to put in opposite control to stop a vertical rate.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y easy because aircraft held altitude – Y-Z a little bit harder because of altitude task – adequate performance with tolerable workload.

- Landing: Could do very easily – stayed rock solid in X-Y – could establish rate very predictably.

TURBULENCE EFFECTS: Not very noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.1/.25	6/6	201C	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Fairly predictable – tendency to wander a lot more than would like in hover.

- **Attitude:** Fairly predictable – response was smoother than before.

- **Height:** Lot of effort in height control – attitude inputs made altitude wander – not holding altitude – altitude rate predictability not as good as I'd like.

- **Precision vs. Gross Maneuvering:** Gross acquisition fairly easy – in hover, had difficulty because of altitude control.

- **Forces, Displacements:** Larger than would like – harmony O.K..

- **Special Control Techniques:** Tended to overcontrol throttle corrections.

TASK PERFORMANCE/WORKLOAD:

- **X-Y-Z:** Workload considerable just for adequate performance -- extensive pilot compensation.

- **Landing:** Had to work pretty hard for adequate performance.

TURBULENCE EFFECTS: Certainly were evident – detrimental.

GENERAL: Height control was objectionable feature – lack of altitude hold.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
3/3/2.5	.1/.5/A	7/6	201D	

RESPONSE TO CONTROL:

- **Translation:** Poor predictability.

- **Attitude:** Predictability fairly good.

- **Height:** Real good predictability.

- **Precision vs. Gross Maneuvering:** Trouble with gross acquisition and hover.

- **Forces, Displacements:** Forces and displacements large – harmony O.K..

- **Special Control Techniques:** Couldn't figure out what would work – problem was large control inputs required.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y easier than Y-Z because of altitude hold, workload (Y-Z) more than would like to accept – adequate performance not attainable with tolerable pilot workload.

- Landing: Once set up was fairly easy to do – easier than X-Y-Z maneuvering – adequate performance with tolerable workload.

TURBULENCE EFFECTS: Annoying because of large inputs required.

GENERAL: Height control good feature – large control inputs (pitch, roll) objectionable.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.1/.5/A	5.5/5.5	201E	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Predictable in gross acquisition – trouble getting squared away in hover.
- **Attitude:** Reasonably predictable.
- **Height:** Quite predictable setting up a rate and stopping it.
- **Precision vs. Gross Maneuvering:** Hover most difficult.
- **Forces, Displacements:** Comfortable, harmony good.
- **Special Control Techniques:** Tendency to overcontrol in X-Y – had to watch inputs.

TASK PERFORMANCE/WORKLOAD:

- **X-Y-Z:** Workload moderate – occasionally got desired performance, mostly adequate – had to work reasonably hard.
- **Landing:** About the same as X-Y-Z.

TURBULENCE EFFECTS: Increased workload, especially in hover.

GENERAL: Altitude control good feature – predictability in translation in hover was objectionable feature.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
3/2/2.5	.1/.5	6/4	201F	

RESPONSE TO CONTROL:

- **Translation:** Predictability not good in gross acquisition – O.K. in hover – getting big translation going the real problem.

- **Attitude:** Initial response sluggish.

- **Height:** Quite easy.

- **Precision vs. Gross Maneuvering:** Gross acquisition most difficult – hover quite easy.

- **Forces, Displacements:** Large forces and displacements to get going.

- **Special Control Techniques:** None other than large inputs.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload high in X-Y gross acquisition – adequate performance, tolerable pilot workload – required extensive compensation.

- **Landing:** Workload lower in hover – adequate performance – tolerable workload – not satisfactory without improvement.

TURBULENCE EFFECTS: Not really detrimental.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.05/.75/A	5/4	202A	Y-Z tracking task and landing only

RESPONSE TO CONTROL:

- **Translation:** Bit sluggish – bit of predictability problem.

- **Attitude:** Fairly predictable.

- **Height:** Predictable – took an awful lot of throttle control to get it going – trouble making small corrections.

- Precision vs. Gross Maneuvering: Hover easier than gross maneuvering because of large stick and throttle inputs required – No undesirable motions.

- Forces, Displacements: Little larger than I'd like – harmony O.K..

- Special Control Techniques: None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Y-Z bit more difficult because it took so long to get rate going in altitude – performance adequate – but moderately hard work – considerable pilot compensation.

- Landing: Got desired performance – moderate pilot compensation.

TURBULENCE EFFECTS: Couldn't sort it out.

GENERAL: Objectionable features were large stick and throttle control throws and sluggishness in pitch/roll attitude.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/5/2.5	.1/.5/A	7/5	202B	

RESPONSE TO CONTROL:

- **Translation:** Control difficult, relatively unpredictable because of trouble with attitude response.

- **Attitude:** Response sluggish — lack of predictability — roll worse than pitch.

- **Height:** Crisp, predictable, held altitude.

- Precision vs. Gross Maneuvering: Gross acquisition real problem — hover not easy but easier than gross maneuvering.

- Forces, Displacements: Large forces and displacements — thought there was some disharmony.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Adequate performance at best.

- **Landing:** Bit easier — bordered on desired performance with considerable workload — not satisfactory without improvement.

TURBULENCE EFFECTS: Appeared to be a problem this time.

GENERAL: Sluggishness and large control inputs were objectionable — good feature was altitude control.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.05/.5/A	4/4	202C	Y-Z tracking and landing only

RESPONSE TO CONTROL:

- **Translation:** Predictable.
- **Attitude:** Predictability good, crisp.
- **Height:** Setting up a rate was predictable – making corrections bit of a problem – throttle movements bit more than I'd like them to be.
- **Precision vs. Gross Maneuvering:** Gross acquisition was primary problem in Y-Z because of altitude – hover was fairly easy – got desired performance, was predictable.
- **Forces, Displacements:** Good in pitch and roll – harmony O.K..
- **Special Control Techniques:** None in particular.

TASK PERFORMANCE/WORKLOAD:

- **X-Y-Z:** Got desired performance in X-Y, more trouble with altitude – workload only moderate -- adequate performance with tolerable workload – not satisfactory without improvement.
- **Landing:** Same for landing – setting up rate of descent required more throttle than I'd like.

TURBULENCE EFFECTS: Got a few heaves back and forth, must have been turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/2/2.5	.1/.5/A	2/2	202D	

RESPONSE TO CONTROL:

- **Translation:** Predictability good.
- **Attitude:** Good predictability
- **Height:** Control easy - held altitude and setting up a rate was predictable.
- **Precision vs. Gross Maneuvering:** Gross acquisition and hover both quite easy to perform - bit of abruptness in attitude when I went after things aggressively but not really objectionable.
- **Forces, Displacements:** Comfortable, harmony good.
- **Special Control Techniques:** None.

TASK PERFORMANCE/WORKLOAD:

- **X-Y-Z:** X-Y got desired performance, workload not very high - Y-Z altitude control added relatively negligible additional work, performance pretty good.
- **Landing:** Could do just what I wanted to.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.15/.5/A	6/5	202E	Y-Z tracking and landing only

RESPONSE TO CONTROL:

- **Translation:** Moderately predictable — little bit sluggish.

- **Attitude:** Moderately predictable — got a little bit sluggish.

- **Height:** Had trouble making corrections and setting up a predictable rate — held altitude however.

- **Precision vs. Gross Maneuvering:** X-Y gross acquisition reasonably easy — had a little trouble with hover — no problem holding altitude — acquisition a little bit difficult, lack of predictability.

- **Forces, Displacements:** Pitch and roll higher than I would like them to be — harmony O.K..

- **Special Control Techniques:** In altitude, had to put in several inputs to get what I wanted.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y got adequate performance. Note — Remainder of comments lost.

- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/3/2.5	.1/.5/Y	5/4	202F	

RESPONSE TO CONTROL:

- **Translation:** Predictability a little bit lacking.

- **Attitude:** Same as translation.

- **Height:** Quite predictable.

- **Precision vs. Gross Maneuvering:** Problem primarily with gross acquisition – hover was more predictable.

- **Forces, Displacements:** Both a little larger than I would like. Harmony was good.

- **Special Control Techniques:** None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: In X-Y tracking, aircraft held altitude – problem was setting up a closure and stopping it – once in hover could hold it pretty well – tracking in Y-Z same as X-Y – adequate performance required considerable compensation.
- **Landing:** Reasonably easy – got pretty good performance – required moderate pilot compensation.

TURBULENCE EFFECTS: Not really noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.1/.5/A	6/3	203A	

RESPONSE TO CONTROL:

- Translation: Predictability just moderate.

- Attitude: Predictability not real good but not bad – attitude response pretty abrupt.

- Height: Quite predictable – airplane tended to hold altitude, could establish a rate pretty well.

- Precision vs. Gross Maneuvering: Had some trouble with gross acquisition, making corrections – once into the hover, could hold it pretty well stabilized.

- Forces, Displacements: Not particularly noticeable – harmony O.K..

- Special Control Techniques: Tendency to slip through the box, had to slow rate at closure, couldn't stop predictably or aggressively – once there it was relatively easy to hold.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Once stabilized got desired performance – workload in acquisition phase was pretty high.

- Landing: Easiest, could hover quite easily and could control altitude pretty well.

TURBULENCE EFFECTS: Not particularly noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/4/2.5	.1/.5/A	8/8	203B	

RESPONSE TO CONTROL:

- Translation: Bad because of very large lag in attitude response.

- Attitude: Control very difficult, sluggish, large forces and displacements to get anything.

- Height: Felt O.K., seemed to hold altitude.

- Precision vs. Gross Maneuvering: Even small corrections in hover were difficult.

- Forces, Displacements: Way too large, pitch and roll.

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Could not get adequate performance with tolerable workload — controllability in a dangerous situation would be in question.

- Landing: As above.

TURBULENCE EFFECTS: Not noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
9/3/2.5	.1/.5/A	5/4	203C	

RESPONSE TO CONTROL:

- Translation: Predictability fairly good, had some trouble making small corrections getting it into the box.
- Attitude: Predictability pretty good – maybe a little bit abrupt.
- Height: Good, would hold altitude, could set up a predictable rate.
- Precision vs. Gross Maneuvering: Hover a little easier.
- Forces, Displacements: Pretty good, didn't notice anything in particular.
- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Performance adequate, bordering on undesired, workload was considerable.
- Landing: Was the easiest part (of task), hovering relatively easy, height control pretty good.

TURBULENCE EFFECTS: Seemed like natural turbulence created some upsets.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/2.5/2.5	.15/.5/A	6/5	203D	

RESPONSE TO CONTROL:

- Translation: Troubles initiating a rate, had to hold fairly large inputs to get decent rate — hover translational control seemed a little easier.

- Attitude: Response predictability not very good.

- Height: Held altitude, could get a predictable rate going.

- Precision vs. Gross Maneuvering: Gross acquisition more difficult in terms of predictability — no undesired motions.

- Forces, Displacements: Felt high to get a decent rate going.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Quite a bit of work to get into the box in time allotted — could get only adequate performance and had to work fairly hard at it.

- Landing: Got desired performance with considerable pilot workload.

TURBULENCE EFFECTS: Fair amount of natural turbulence upsetting the aircraft.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
3/4/2.5	.1/.5/A	4.5/4	203E	

RESPONSE TO CONTROL:

- Translation: Something missing, couldn't put my finger on it.

- Attitude: Response predictable.

- Height: Control quite good, held altitude and could set up a rate.

- Precision vs. Gross Maneuvering: Problem in gross acquisition, could hold a hover better — no undesirable motions.

- Forces, Displacements: Felt O.K., maybe a little high — harmony was O.K..

- Special Control Techniques: Much less trouble with roll than pitch — Could be because winds were changing — so tendency to drift longitudinally.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired performance if I worked very hard, otherwise just adequate — problems were in longitudinal/lateral.

- Landing: Once established in hover, could hold fairly easily.

TURBULENCE EFFECTS: Seemed to be there.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/2/2.5	.1/.5/A	4/3	204A	

RESPONSE TO CONTROL:

- Translation: Could initiate translation and stop it predictably once I figured out what my altitudes needed to be.

- Attitude: Predictability pretty good, quick initial response, little bit jerky.

- Height: Little bit of trouble with predictability setting up a rate.

- Precision vs. Gross Maneuvering: X-Y pretty good – problem was primarily in vertical tracking predictability.

- Forces, Displacements: Comfortable, didn't notice them. Harmony adequate.

- Special Control Techniques: None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y performance pretty good, workload not very high. Y-Z difficult because of height, had to use large throttle to get things going then back off. To stop had to use throttle in opposite direction.

- Landing: Not that difficult to set up steady rate.

TURBULENCE EFFECTS: Didn't seem to be dominant.

GENERAL: CHPR = 4 for X-Y-Z tracking primarily due to vertical. Altitude tended to wander a little for X-Y inputs.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/3/2.5	.1/.5/A	5/4	204B	

RESPONSE TO CONTROL:

- Translation: Response predictable although had a tendency to get bigger inputs than desired, some trouble with predictability in hover.

- Attitude: Response predictable.

- Height: Essentially same as last time. Height wanders with X-Y inputs – appeared to be a height hold situation, some problems with Z predictability.

- Precision vs. Gross Maneuvering: Hover more difficult – gross acquisition easy to initiate, got predictable rates but tended to be a little bit higher than desired sometimes.

- Forces, Displacements: Stick softer than last time – May have led to inadvertent inputs – trouble hovering attributed to lower forces in pitch and roll.

- Special Control Tecnniques: Had to pay a lot more attention.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Acquisition part not particularly difficult, sometimes closures higher than desired – had trouble with hover, more attention, higher workload to get desired performance – in Y-Z, situation compounded by problems with height control.

- Landing: More difficult because of troubles hovering – got desired performance but had to work moderately hard.

TURBULENCE EFFECTS: Thought they were there.

GENERAL: CHPR = 5 for tracking attributed to hover problems.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
6/3/2.5	.1/.5/A	6/5	204C	

RESPONSE TO CONTROL:

- Translation: Had some difficulties with getting something going, some problems with predictability in hover.

- Attitude: Response fairly predictable, didn't have any trouble with that.

- Height: Had problems with predictability in acquiring a new height.

- Precision vs. Gross Maneuvering: Trouble initiating gross acquisition in hover, tended to dance around more than I'd like to – primary reason for problem was large control displacements but forces were O.K..

- Forces, Displacements: To initiate motion, needed large inputs then had to back off – harmony felt O.K..

- Special Control Techniques: Put in big input then back off, X-Y and Z.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Most of the time just adequate performance and had to work fairly hard, especially in hover.

- Landing: Got adequate performance, had to work fairly hard at it.

TURBULENCE EFFECTS: Thought they were there – thought some of the problems in hover were due to turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/2.5/2.5	.1/.5/A	4.5/4	204D	

RESPONSE TO CONTROL:

- Translation: Initial predictability not good, felt sluggish – took quite a bit of input to get going, tended to get more response than desired.

- Attitude: Predictability not bad initially but seemed to change a little bit with a steady input.

- Height: Same as before – held altitude but tended to move around more than would like – wasn't as tight as would like it to be – trouble setting up predictable rates.

- Precision vs. Gross Maneuvering: Gross acquisition difficult because of large inputs required to get it going – once near the box I was able to hold it pretty well.

- Forces, Displacements: Took large stick inputs – noticed the force especially the initial as opposed to the final – harmony felt O.K..

- Special Control Techniques: None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got adequate bordering on desired – biggest part of workload was to set up the hover – problems in Y-Z because of height control, added to troubles of getting predictable lateral closure going.

- Landing: Adequate performance with tolerable pilot workload – had some trouble setting up a good rate of sink.

TURBULENCE EFFECTS: Weren't very apparent.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/2/2.5	.15/.75/A	2/2	205A	

RESPONSE TO CONTROL:

- Translation: Pretty good.

- Attitude: Predictability pretty good.

- Height: I liked that.

- Precision vs. Gross Maneuvering: Able to initiate a response, could get predictable rate going – hover fairly easy to do.

- Forces, Displacements: Initially felt a little high – finally felt pretty good both in initial and final part of response.

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired performance, workload fairly light.

- Landing: Could hold hover, good predictability of rate of sink – got desired performance, workload was pretty low.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/4/2.5	.15/.75/A	7/6	205B	

RESPONSE TO CONTROL:

- Translation: Difficult to get started, tended to get too much, had trouble stopping, so predictability poor.

- Attitude: Predictability poor in terms of getting started and then wandering in relation to input.

- Height: Really good.

- Precision vs. Gross Maneuvering: Both equally bad, corrections difficult, couldn't get it going.

- Forces, Displacements: Large forces and displacements to get it going so, initial part, uncomfortably large, final part (of response) O.K..

- Special Control Techniques: Slowed down rate of closure as I approached the box.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Could get adequate performance but workload was excessive.

- Landing: Had trouble holding the spot (X-Y) whereas height control was real easy.

TURBULENCE EFFECTS: Some wandering due to airplane reacting to turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/3/2.5	.15/.75/A	3/2	206A	

RESPONSE TO CONTROL:

- Translation: Control quite good, little bit of trouble in the hover.
- Attitude: Response predictability quite good.
- Height: Control quite predictable -- could initiate a rate of sink predictably and stop it and it held altitude.
- Precision vs. Gross Maneuvering: Biggest problems were in hover, think because of winds drifting me around, not able to fiture out attitude to hold hover.
- Forces, Displacements: Comfortable all the way round, forces may have been a little bit high laterally.
- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:
- Landing: Could do pretty well with minimal workload.

TURBULENCE EFFECTS: Would surmise that simulated turbulence had little effect -- natural turbulence had effect.

GENERAL: Lots of vibration in airplane because of (natural) winds.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/2.5	.15/.75/A	4/2	206B	

RESPONSE TO CONTROL:

- Translation: Had little bit of trouble, felt a little loose in trying to acquire the box, once in hover felt O.K..
- Attitude: Reasonably predictable.
- Height: Good.
- Precision vs. Gross Maneuvering: If any problems, it was in gross acquisition — no undesirable motions.
- Forces, Displacements: Forces a little lighter than last time, bit more comfortable — harmony good.
- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Difficulty stopping in box — able to get at least adequate to desired performance, workload only moderate.
- Landing: Once in hover could stay there — could do landing task fairly well, low workload.

TURBULENCE EFFECTS: Natural turbulence noticeable, trouble sorting out attitude to stay over a spot.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/4/2.5	.15/.75/A	6/6	206D	

RESPONSE TO CONTROL:

- **Translation:** Was a problem.
- **Attitude:** Predictability adequate.
- **Height:** Good, no problem there.
- **Precision vs. Gross Maneuvering:** Trouble with gross acquisition and hover. Could set up rate but had trouble stopping and making corrections in hover.
- **Forces, Displacements:** Large forces and displacements - no harmony problems.
- **Special Control Techniques:** None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Tracking X-Y was problem, workload large for adequate performance.
- Landing: Could get adequate performance but took a lot of workload - problems with small (X-Y) corrections.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.5/2.5	.15/.75/A	7/7	206C	

RESPONSE TO CONTROL:

- Translation: Airplane stiff in translation, hard time starting, couldn't get as much rate as I wanted, trouble stopping.

- Attitude: Predictability not real good — seemed to follow inputs then felt like (response) was washing out.

- Height: Good, could set up desired rate of closure.

- Precision vs. Gross Maneuvering: Had particular trouble with gross acquisition — when disturbed in hover, required large inputs for correction and they were uncomfortable — gross acquisition and hover predictability not very good.

- Forces, Displacements: Large inputs required, occasionally full deflection particularly in roll. (Lack of) harmony not obvious, sometimes felt roll heavier than pitch.

- Special Control Techniques: None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Could barely get adequate performance, couldn't do it with a tolerable pilot workload.

- Landing: Had trouble holding hover (i.e., X-Y position), rate of sink not a problem — could not get adequate performance with tolerable workload for landing.

TURBULENCE EFFECTS: Turbulence affected this airplane,maybe inability to deal with disturbances made it more obvious.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/3/2.5	.15/.75/A	5/5	206F	

RESPONSE TO CONTROL:

- Translation: Airplane felt loose in translation.

- Attitude: Predictability only moderate, but sluggish coming on, did funny things while holding input.

- Height: Good, didn't see any problems.

- Precision vs. Gross Maneuvering: Problem primarily in gross acquisition although hover was none too easy.

- Forces, Displacements: Forces felt fairly light – displacement felt fairly large in gross acquisition – there was a mismatch there.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Adequate performance but had to work reasonably hard – had some predictability problems – the thing that made it easier this time was the forces were more reasonable.

- Landing: Adequate performance with tolerable but considerable workload due to predictability problems.

TURBULENCE EFFECTS: Seemed to be there – couldn't sort out whether it was natural or synthetic but I was being bounced around.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
13/4/2.5	.15/.75/A	4.5/3	207A	

RESPONSE TO CONTROL:

- Translation: Predictability good in getting started — trouble in stopping it — seemed to be a lag in translational response when making corrections.

- Attitude: Predictability reasonably good, a little jerky initially.

- Height: Good — held altitude — could set up a rate easily.

- Precision vs. Gross Maneuvering: Biggest problem was predicting the corrections to stop in the box.

- Forces, Displacements: Forces comfortable, relatively light, displacements reasonable, harmony pretty good.

- Special Control Techniques: Had to be careful not to overcontrol.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired performance but workload was pretty considerable.

- Landing: Got desired performance — didn't have to work particularly hard.

TURBULENCE EFFECTS: Not really noticeable — no natural turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/2.25/2.5	.15/.75/A	3.5/?	207B	

RESPONSE TO CONTROL:

- Translation: Thought initially it would be soft with predictability problems — seemed to work out to be better than last time.

- Attitude: Initial predictability pretty good, then felt like I was getting some washout.

- Height: Pretty good, no problem.

- Precision vs. Gross Maneuvering: Could initiate an acquisition pretty well and could stop it better than last time, not sure why.

- Forces, Displacements: Forces good, displacements a little high.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired performance, didn't have to work hard for it.

- Landing: Same as X-Y-Z.

TURBULENCE EFFECTS: Not noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
8/2/2.5	.15/.75/A	3.5/2	207C	

RESPONSE TO CONTROL:

- Translation: At first, had trouble stopping when trying to acquire the target – then translational control became quite predictable, was able to stay in slot once I got there.

- Attitude: Predictability pretty good – initial response too abrupt.

- Height: Easy.

- Precision vs. Gross Maneuvering: Early in evaluation, had trouble with gross acquisition, hover was easy.

- Forces, Displacements: Both comfortable.

- Special Control Techniques: I did something different as evaluation went along, can't describe it.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired performance, initially workload was high but then got down to the moderate level.

- Landing: Got desired performance with no problem.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
8/3.5/2.5	.15/.75/A	5.5/4	207D	

RESPONSE TO CONTROL:

- Translation: Problems with predictability in translational control, when aggressive tended to overcontrol.

- Attitude: Felt soft in attitude.

- Height: good.

- Precision vs. Gross Maneuvering: In hover was not aggressive and had no problems – in the gross acquisition, had a tendency to overshoot the target, had to use large inputs to get things started – some problem with predictability there.

- Forces, Displacements: Had to use large forces and displacements to get an adequate closure rate started.

- Special Control Techniques: If aggressiveness kept down, could get desired performance.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Performance was adequate but workload was considerable.

- Landing: Could do job and get desired performance but had to do a little more work to not overcontrol my corrections.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6.5/2.5/2.5	.15/.75/A	5.5/4	207E	

RESPONSE TO CONTROL:

- **Translation:** Tendency to overshoot with aggressive inputs.

- **Attitude:** Predictability not bad but it felt somewhat soft.

- **Height:** No problem.

- **Precision vs. Gross Maneuvering:** Large inputs to get things going — if tried to stop aggressively, got overshoot — If I took my time, could get it in and get desired performance — Because of smaller inputs, didn't have any trouble with hover.

- **Forces, Displacements:** Both felt large.

- **Special Control Techniques:** Had to take your time, not be aggressive.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Could get adequate performance with considerable pilot compensation.

- Landing: Had to work to stay in box — stay unaggressive and things work out pretty well.

TURBULENCE EFFECTS: Not noticed.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5.5/2.75/2.5	.15/.75/A	6/4	208A	

RESPONSE TO CONTROL:

- Translation: - sluggish initially then more sluggish as forces heavied up when trying to hold a rate - had some problems with overcontrolling acquisition of the target - trouble with hover, had to work hard to get into box.
- Attitude: - Not bad but felt a little bit sluggish.
- Height: - good, no problem, very precise, very steady.
- Precision vs. Gross Maneuvering: - gross maneuvering a problem hover was a problem if disturbed significantly.
- Forces, Displacements: - initial forces and displacements comfortable, final heavy - no harmony problems.
- Special Control Techniques: - must be careful not to let large disturbances come up because they were a little bit more difficult to control.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - no better than adequate, had to work fairly hard to do that.
- Landing: - adequate bordering on desired performance but had to work pretty hard atiit.

TURBULENCE EFFECTS: - wandering more in hover than on earlier flights, could be wind - had some difficulty establishing a good hover position so landing task was harder.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/2.5	.15/.75/A	4/3	208B	

RESPONSE TO CONTROL:

- Translation: - snappy getting started - some trouble in predictability of corrections trying to stop in the box.

- Attitude: - initial response quite predictable.

- Height: - not a problem.

- Precision vs. Gross Maneuvering: - primary problems in gross maneuvering - hover seemed pretty good.

- Forces, Displacements: - comfortable pitch and roll - harmony o.k.

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performance - had to work reasonably hard

- Landing: - got desired performance - didn't have to work particularly hard.

TURBULENCE EFFECTS: - bouncing around in hover more than in first flight - having trouble holding position - don't know whether its the configuration or the atmosphere.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
		4/--	208C	

RESPONSE TO CONTROL:

- Translation: Comments lost.

- Attitude:

- Height:

- Precision vs. Gross Maneuvering:

- Forces, Displacements:

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:

- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
12/2/2.5	.15/.75/A	3/4	209A	

RESPONSE TO CONTROL:

- Translation: - predictable.

- Attitude: - predictability good - quick initial response - perhaps a little too abrupt.

- Height: - real good.

- Precision vs. Gross Maneuvering: - gross maneuvering a bit easier - good airplane sensitive, had to work harder not to overcontrol (in hover) - had a little bit more trouble holding the hover if I was doing a vertical maneuver.

- Forces, Displacements: - comfortable, nice and light - displacements small, harmony felt good.

- Special Control Techniques: - for landing, had to avoid inadvertent inputs which disturb the airplane.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performance - didn't have to work all that hard for it.

- Landing: - little more difficult than gross maneuvering - adequate bordering on desired performance - work load little bit higher than maneuvering.

TURBULENCE EFFECTS: - didn't notice any.

GENERAL: - airplane abrupt, really jittery.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/3/2.5	.15/.75/A	7/5	209B	

RESPONSE TO CONTROL:

- Translation: - tendency to overcontrol, particularly if I tried to be aggressive.

- Attitude: - predictability lousy - very sluggish initial response.

- Height: - good - when I concentrated on height control X-Y control problems developed which led to height control problems.

- Precision vs. Gross Maneuvering: - airplane didn't move fast enough - - no undesirable motions - had to time recoveries, otherwise skidded past target - hover difficult, tendency to overcontrol.

- Forces, Displacements: - large force and displacement to get airplane moving - in steady part, forces felt comfortable - forces initially heavy then lighten up - harmony ok.

- Special Control Techniques: - could get adequate performance if not overly aggressive, otherwise could get in trouble.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - performance adequate - workload pretty high, extensive, - height control even though good, detracted from X-Y.

- Landing: - adequate performance - considerable pilot workload.

TURBULENCE EFFECTS: - airplane moved with turbulence - little bit more than last time.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/1.5/2.5	.15/.75/A	3/2	209C	

RESPONSE TO CONTROL:

- Translation: - predictability pretty darn good - could start and stop predictability.
- Attitude: - predictable response - good initial response.
- Height: - good.
- Precision vs. Gross Maneuvering: - expected jerky airplane response but didn't get it - pretty good from that point of view.
- Forces, Displacements: - didn't take a whole lot of force to get going but when forces heavied up during a translation - not particularly high but noticeable - harmony pretty good.
- Special Control Techniques: - none.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - desired performance with relatively low workload.
- Landing: - performance so good that I did landings with Y-Z tracking task on- satisfactory without improvement.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
12/3/2.5	.15/.75/A	6/5.5	209E	

RESPONSE TO CONTROL:

- **Translation:** Started moving when I wanted to but had trouble stopping – felt like it had a drift – trouble predicting steady rates.

- **Attitude:** Predictable in terms of starting to go.

- **Height:** Pretty good – no problem there.

- **Precision vs. Gross Maneuvering:** Had trouble with drift both in gross acquisition and hover – no undesirable motions.

- **Forces, Displacements:** Reasonably comfortable – didn't notice anything in particular.

- **Special Control Techniques:** Tried not to let errors build up in hover because of problems dealing with them.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got adequate performance but had to work extensively.

- Landing: Got adequate performance but had problems holding the hover – not satisfactory without improvement – required considerable compensation.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
13/2.5/2.5	.15/.75/A	4.5/3	211A	

RESPONSE TO CONTROL:

- **Translation:** Could get things going pretty well initially, got a reasonable closure rate then had bit of difficulty stopping – difficulty correcting for drift and in hover.

- **Attitude:** Predictable, abrupt, kind of oscillatory and high frequency after the initial input.

- **Height:** Quite easy, held altitude, could develop a rate when I wanted.

- **Precision vs. Gross Maneuvering:** Tail end of gross acquisition and some aspects of hover had predictability difficulties – abruptness and ringing in attitude was undesirable to some degree.

- **Forces, Displacements:** Comfortable, harmony O.K..

- **Special Control Techniques:** Had to be aggressive with errors – grab them before they get large.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y biggest problems with corrections – get desired performance but had to work pretty hard – Y-Z no different – required moderate to bit more than moderate compensation.

- Landing: Once established in hover landing worked out pretty well – got desired performance, only had to work moderately hard – minimal compensation required.

TURBULENCE EFFECTS: Tended to drift in hover, don't know whether due to turbulence or problems with corrections.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
3.5/1.5/2.5	.15/.75/A	4.5/3	211B	

RESPONSE TO CONTROL:

- **Translation:** Could get closure going but rate not very predictable — to arrest rate had to use aggressive, large inputs, had to overdrive airplane — had to use large inputs even in hover.

- **Attitude:** Predictability not all that great, plane did not respond immediately — after input airplane did some things that weren't commanded.

- **Height:** Fairly easy, held altitude, occasionally wandered off a bit — predictability good.

- **Precision vs. Gross Maneuvering:** Problem primarily in gross acquisition — hover reasonably predictable but needed large inputs — attitude didn't always do what I commanded.

- **Forces, Displacements:** Initial not all that high but to keep a closure going, the forces got pretty high — displacements weren't all that noticeable, just forces.

- **Special Control Techniques:** Had to horse it around to get desired performance.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y got desired performance — had to work hard. Y-Z essentially the same, took care of altitude fairly quickly.

- Landing: Easier, didn't require large corrections once I got established — could set up sink rate predictably.

TURBULENCE EFFECTS: Didn't notice any.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
10/1.5/2.5	.15/.75/A	4/--	211C	Partial evaluation

RESPONSE TO CONTROL:

- **Translation:** Predictability was so-so — wasn't real predictable — required manhandling the airplane in attitude — tendency to overdo it because of sensitivity.

- **Attitude:** Certainly got instantaneous response — too abrupt, jumpy.

- **Height:** Good, no problems there.

- **Precision vs. Gross Maneuvering:** Problems primarily in gross acquisition — hover not all that difficult — airplane way too jumpy.

- **Forces, Displacements:** Forces very, very light — seemed to heavy up trying to acquire the target — didn't notice harmony.

- **Special Control Techniques:** Had to manhandle the airplane but there was a tendency to put in too large inputs.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: X-Y got adequate performance bordering on desired — workload considerable — not as hard as last time because forces were lighter — no Y-Z evaluation.

- Landing: Not evaluated.

TURBULENCE EFFECTS: Weren't any noticeable — tended to drift during initial part of evaluation.

GENERAL: Similar to last one but very sensitive.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
12/3/2.5	.15/.75/A	6/5.5	209E	

RESPONSE TO CONTROL:

- Translation: - started moving when I wanted to but had trouble stopping, felt like drift - had trouble predicting steady rates.

- Attitude: - predictable in terms of initially starting to go.

- Height: - pretty good - no problem.

- Precision vs. Gross Maneuvering: - trouble in both - response not proportional to input - bothersome in small corrections too, carried over into hover.

- Forces, Displacements: - reasonably comfortable - harmony o.k.

- Special Control Techniques: - tried not to let errors build up because had problems dealing with them.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance but workload was extensive

- Landing: - adequate performance but had some problems holding hover.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
6/3/2.5	.15/.75/A	3/-	212D	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - predictable - airplane moved around a little bit but didn't compromise positioning.

- Attitude: - predictable

- Height: - easy

- Precision vs. Gross Maneuvering:
  - turbulence noticeable but didn't compromise ability to hover.

- Forces, Displacements:
  - both a bit high.

- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - desired performance, nominal workload.

- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
Att.Command 2.5 r/s.6 deg/in	.15/.75/A	4.5/-	212E	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - could get things started when I wanted to - seemed like I was able to get a steady state rate going.

- Attitude: - initial response occurred when I made input but moved around for steady state (constant) input-objectionable and noticeable.

- Height: - no problems - small corrections required when doing crossed inputs - was holding altitude pretty steady

- Precision vs. Gross Maneuvering:
  - biggest problem with stopping aircraft over a point after a translation - wasn't real bad but more difficult than last time.

- Forces, Displacements:
  - a little high, but not uncomfortable harmony o.k.

- Special Control Techniques:
  - had to monitor more after stopping over a point than the last time as to whether I was going to stay there or not.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - desired performance required moderate to considerable pilot compensation.

- Landing:

TURBULENCE EFFECTS:- larger in this airplane than the last one.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/2.5	.15/.75/A	4/-	212F	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - one of those airplanes that you get started but then it wants to stop - takes increasing effort to keep it going -predictability was pretty good.

- Attitude: -

- Height: - No problem.

- Precision vs. Gross Maneuvering: - Gross maneuvering was the most problem - had to modulate input to keep the translation going - not dangerous, just have to work a little harder - hover fairly easy, no trouble stopping on a point and holding position.
- Forces, Displacements:
  - comfortable initially but then too high in trying to keep a translation going - harmony o.k.

- Special Control Techniques: - none.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performances - workload high from having to modulate input to keep response going - aircraft was predictable.

- Landing:

TURBULENCE EFFECTS: - some effect but not a whole lot.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
9/3/2.5	.15/.75/A	5/-	212G	Gnd. Ref. Task

RESPONSE TO CONTROL:

- Translation: - not too bad - some difficulty because attitude didn't settle down right away - impression that airplane wanted to drift.

- Attitude: - predictability wasn't bad - some dancing around in attitude - degraded ability to know exactly where I was going to go.

- Height: - no problem.

- Precision vs. Gross Maneuvering: - gross maneuvering, same problem as previous case - things would start going then had to put in increasing force to keep it going - that was undesirable - hover, was able to hold ptetty well but had to monitor a bit more because of impression that it wanted to drift.
- Forces, Displacements:
  - Little bit lighter than previous configuration - bit more comfortable but forces build-up as you translate over the ground.

- Special Control Techniques: - none in particular except paying more attention.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate bordering on desired performance - required considerable pilot compensation.

- Landing:

TURBULENCE EFFECTS: - don't know whether drifting around was due to turbulence or the airplane.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
8/2/3	.15/.75/A	4.5/4	213A	

RESPONSE TO CONTROL:

- Translation: - not too bad but tended to drift when stopped over target.
  - worked reasonably hard in hover - not sure why.

- Attitude: - predictable but abrupt.

- Height: - clearly not a problem.

- Precision vs. Gross Maneuvering: - predictability getting started o.k.
  - problem in stopping.

- Forces, Displacements:
  - didn't notice displacements, forces seemed high in gross maneuvers - initial and final both high, harmony O.K..

- Special Control Techniques:
  - better to not try to stop aggressively - tried to slip it into the groove.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate bordering on desired performance - workload fairly considerable.

- Landing: - once set up in hover, could hold hover and get desired performance for landing - moderate pilot compensation.

TURBULENCE EFFECTS: - couldn't really tell - didn't seem to be any natural turbulence.

GENERAL: - during first several minutes, sun reflections made HUD hard to see.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/2.5/3	.15/.75/A	7/4	213B	

RESPONSE TO CONTROL:

- Translation: - sluggish - large forces to get started and large forces to keep going - tended to overcontrol on corrections.

- Attitude: - initial response sluggish - felt like airplane stuck in glue.

- Height: - no problem at all.

- Precision vs. Gross Maneuvering:
  - problems are primarily in gross maneuvering - once in hover it seemed o.k., turbulence didn't make much difference.

- Forces, Displacements:
  - hovering with sideslip to avoid HUD reflections - right forces higher than left - roll felt higher than pitch - both were large - uncomfortable.

- Special Control Techniques: - had to get right on top of corrections.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance in X-Y but no better - workload large - workload bit higher in Y-Z.

- Landing: - desired performance with moderate pilot compensation.

TURBULENCE EFFECTS: - not noticeable - felt like it was in molasses.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/3/3	.15/.75/A	4.5/4	213C	

RESPONSE TO CONTROL:

- Translation: - could get things started, get reasonable rate going - problems with overcontrolling corrections when I got into target.
- Attitude: - predictability pretty good.
- Height: - easy - no problem.
- Precision vs. Gross Maneuvering: - gross maneuvering went fairly predictably - only problems were corrections at end - reasonably predictable for hover.
- Forces, Displacements: - forces were comfortable - displacements good - harmony o.k.
- Special Control Techniques: - didn't use any in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance bordering on desired - workload was considerable.
- Landing: - desired performance but had to work moderately hard.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
13/2.5/2.5	.15/.75/A	3/-	213E	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - good control.

- Attitude: - predictability real good.

- Height: - no problem.

- Precision vs. Gross Maneuvering:
  - gross maneuvering, no trouble translating, could stop where I wanted to with no skidding no undesirable motions.

- Forces, Displacements:
  - felt comfortable - harmony o.k.

- Special Control Techniques: - no special techniques.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance, minimal pilot compensation comfortable.

- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/1.5/2.5	.15/.75/A	7/4	214A	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - lag on initial response - had to increase force to keep going, particularly in lateral.
- Attitude: - initially soft - tendency to oscillate after step input.
- Height: - no problem.
- Precision vs. Gross Maneuvering: - tendency to oscillate, especially in roll - at one point had full lateral control and airplane seemed to roll in wrong direction.
- Forces, Displacements: - large especially to hold a steady translational rate.
- Special Control Techniques: - Once you get a rate going, increase control to keep it going.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance not attainable with extensive pilot maneuvering compensation.
- Landing: - desired performance, moderate compensation hover.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
13/4/2.5	.15/.75/A	5/4½	214B	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - predictability felt better - bit slow getting going - tended to overshoot in stopping.

- Attitude: - predictability not bad - bit slow in initial response - didn't do all the wiggles like the last one - noticed washout after input - not as noticeable as last one.

- Height: - easy, no problem

- Precision vs. Gross Maneuvering: - problems at tail end of gross acquisition trying to stop or point - also more work in hover because it is more susceptable to turbulence.

- Forces, Displacements: - still somewhat high - not as bad as last time - lot more comfortable - harmony O.K.

- Special Control Techniques: - had to spend more time with small corrections.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - - performance adequate - had to work moderately hard to get adequate performance.

- Landing: - moderate bordering on desired - not as good as last one, workload clearly higher.

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
12/2/2.5	.15/.75/A	4/3	214C	Gnd Ref. Task

RESPONSE TO CONTROL:

- Translation: - could get it going and could stop it when I wanted to.
- Attitude: - predictability good - a little abrupt - could get what I wanted and it would stay in there - washout not very noticeable - it was acceptable.
- Height: - good control.
- Precision vs. Gross Maneuvering: - felt pretty good in precision and gross maneuvers - easy to hold hover - aircraft had tendency to respond to turbulence a bit more than expected.
- Forces, Displacements: - pretty comfortable - harmony o.k.
- Special Control Techniques: - I was a little bit careful with initial inputs to avoid abrupt response.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performance - didn't have to work all that hard for it - abruptness is annoying and causes concern.
- Landing: - abruptness less noticeable - desired performance with minimal pilot compensation.

TURBULENCE EFFECTS:

GENERAL: - abruptness was a little noticeable, a little worrisome.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
8/1.5/2.5	.15/.75/A	2/2	214H	Gnd. Ref. Task

RESPONSE TO CONTROL:

- Translation: - response was good - bit of a washout at the end, not bothersome.
- Attitude: - attitude response predictability was good.
- Height: - control was good.
- Precision vs. Gross Maneuvering: - both good.
- Forces, Displacements: - comfortable, initial and final.
- Special Control Techniques: - none - felt very comfortable with airplane.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance definitely attainable with tolerable pilot workload in maneuvering and hovering.
- Landing:

TURBULENCE EFFECTS: - not very strong.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/2/3	.15/.75/A	4/4	215D	

RESPONSE TO CONTROL:

- Translation: - predictable - slight tendency to skid when stopping or in hover.
- Attitude: - predictability pretty reasonable.
- Height: - no problem.
- Precision vs. Gross Maneuvering: - looseness in positioning accuracy at tail end of gross acquisition and in hover.
- Forces, Displacements: - forces a little high - didn't notice displacements.
- Special Control Techniques: - try not to be too aggressive - tendency to overcontrol of aggressive.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - desired performance with moderate compensation.
- Landing: - wasn't any better than tracking task due to tendency to skid a little bit.

TURBULENCE EFFECTS: - weren't all that noticeable - maybe was causing wander and drift from position.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
1.5/2.5/3	.15/.75/A	4/3	215E	

RESPONSE TO CONTROL:

- Translation: - could get things going - got pretty good feel for closure rate - could stop it on a dime.

- Attitude: - predictability pretty good - jumpy though, very abrupt.

- Height: - pretty good. problem.

- Precision vs. Gross Maneuvering: - pre good both in gross maneuvering and hover but som ndency to overcontrol occasionally.

- Forces, Displacements: - felt comfo able but (control) sensitivity worked against you a little bit.

- Special Control Techniques: - watch the size of corrections to prevent overcontrol.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - desired performance with moderate compensation - degrading item w s watching size of inputs.

- Landing: - easier (than X-Y-Z tracking) because control inputs required are smaller.

TURBUL E EFFECTS: - not really noticeable.

GENERAL: - abruptness was undesirable.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK, LNDG		
6/3/2	.15/.75/A	8/8	216A	

RESPONSE TO CONTROL:

- Translation: - response very sluggish.

- Attitude: - response predictability very poor, very sluggish.

- Height: - O.K.

- Precision vs. Gross Maneuvering: - couldn't get things started, then got more than I wanted, couldn't get it to stop.

- Forces, Displacements: - displacements required were so large the forces tended to build up - harmony O.K.

- Special Control Techniques: - really had to anticipate.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - could not get adequate performance with tolerable pilot workload.

- Landing: - troubling holding hover.

TURBULENCE EFFECTS: - masked by aircraft problems.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/3	.15/.75/A	4.5/3	216B	

RESPONSE TO CONTROL:

- Translation: - could get things going when I wanted to - little bit of trouble stopping in target area.

- Attitude: - quite predictable - thought there was a little abruptness, think was in the control; airplane felt fairly smooth.

- Height: - no problem.

- Precision vs. Gross Maneuvering: - problems at tail end of gross maneuvers, trying to stop in box - occasionally, couldn t correct hover errors, may have been because of wind changes.

- Forces, Displacements: - comfortable in both force and displacement - harmony o.k.

- Special Control Techniques: - none in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performance most of time - occasionally had problems finding pitch attitude to try to get me to move.

- Landing: - got desired performance with reasonable workload.

TURBULENCE EFFECTS: - felt like a significant amount of ambient turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/2	.15/.75/A	5/4	216D	Syn. turb. = 0

RESPONSE TO CONTROL:

- Translation: - could get things started and stopped in lateral - more difficulty in longitudinal, maybe due to changing winds.

- Attitude: - initial response predictable, final response unpredictable, went to different values - trouble finding pitch attitude, to hold position in varying winds.

- Height: - no problem.

- Precision vs. Gross Maneuvering: - problems in tail end of gross acquisition. Undesirable uncommand pitch attitudes didn't feel connected in pitch attitude.

- Forces, Displacements: - fairly comfortable, weren't noticeable.

- Special Control Techniques: - nothing worked for problem in pitch.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance only with considerable workload.

- Landing: - desired performance with considerable compensation.

TURBULENCE EFFECTS: - noticeable but not obvious what it was doing.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/2	.15/.75/A	5/4	217A	

RESPONSE TO CONTROL:

- Translation: - sluggish getting started, hard to stop aggressively on target.
- Attitude: - predictability not great - tended to be sluggish - drifted a little after inputs.
- Height: - good - no problems.
- Precision vs. Gross Maneuvering: - biggest problem, getting aggressively into the target and stopping after a translation.
- Forces, Displacements: - comfortable in pitch and roll - harmony O.K.
- Special Control Techniques: - because of sluggish attitude, wanted to anticipate - extra attention degraded X-Y performance.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate bordering on desired — performance attainable with tolerable pilot workload.
- Landing: - not satisfactory without improvement, desired performance required moderate compensation.

TURBULENCE EFFECTS: - no comment.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/3	.15/.75/A	3/2	217 B	

RESPONSE TO CONTROL:

- Translation: - predictability good - could start and stop the way I wanted to.

- Attitude: - tended to be abrupt, jerky - the only thing I didn't like about airplane.

- Height: - good.

- Precision vs. Gross Maneuvering: - no difference.

- Forces, Displacements: - comfortable - harmony good.

- Special Control Techniques: - not needed.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance, tolerable workload. Only deficiency is jerkiness – worried me to put in large inputs.

- Landing: - large inputs not required so abruptness no problem.

TURBULENCE EFFECTS: - no comment.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
9/3/2.5	.15/.75/A	5/4	217C	Syn. turb. = 0

RESPONSE TO CONTROL:

- **Translation:** - Occasionally got bigger rates then expected - started pretty well - trouble predicting steady state and stopping.
- **Attitude:** - response a little soft (sluggish)
- **Height:** - O.K.
- Precision vs. Gross Maneuvering: - biggest problems with large corrections - hover not too bad.
- Forces, Displacements: - harmony O.K.
- Special Control Techniques: - tried not to approach pad with excessive (translational) rate.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate performance - required fair amount of pilot compensation
- Landing: - clearly easier - got desired performance with moderate compensation.

TURBULENCE EFFECTS: - tended to drift a little but - maybe due to external (real) turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/3	.15/.75/A	4/3	217D	

RESPONSE TO CONTROL:

- Translation: - pretty good - initially had trouble figuring out attitude to hold against wind.
- Attitude: - response predictability pretty good.
- Height: - no problem.
- Precision vs. Gross Maneuvering:
- Forces, Displacements: - good - harmony O.K.
- Special Control Techniques: - none in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performance, moderate compensation.
- Landing: - predictable - desired performance.

TURBULENCE EFFECTS: - aircraft danced around - attributed to turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
8/1.5/2.5	.15/.75/A	4/3	218E	

RESPONSE TO CONTROL:

- Translation: - could get predictable rate and stop fairly predictably.
- Attitude: - predictable, abrupt, feeling of jiggling in the final response.
- Height: - good.
- Precision vs. Gross Maneuvering: - both good - abruptness of attitude response made me shy about aggressive corrections.
- Forces, Displacements: - comfortable, harmony good.
- Special Control Techniques: - none.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - got desired performance - workload no more than moderate - had to watch inputs because of attitude abruptness.
- Landing: - satisfactory without improvement.

TURBULENCE EFFECTS: - no comment.

GENERAL: - because of abruptness, it is not satisfactory without improvement.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/2.5	.15/.75/A	4.5/2	218F	Syn. turb. = 0

RESPONSE TO CONTROL:

- Translation: - bit of a lag starting things off - biggest problem was stopping - got better toward the end(of the evaluation).

- Attitude: - predictable but came on rather softly.

- Height: - no problem.

- Precision vs. Gross Maneuvering: - gorss maneuvering was problem - once stopped it was steady as a rock.

- Forces, Displacements: - comfortable - harmony was good.

- Special Control Techniques: - did not keep translational rate all the way to the tune that I wanted to stop.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - desirable but occasionally just adequate - tolerable pilot workload.

- Landing: - quite easy - compensation small.

TURBULENCE EFFECTS: - no effect of turbulence.

GENERAL: - performance/workload improved during the evaluation.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/1.5/2.5	.15/.75/A	3 (hover only)	218G	Ground referenced maneuvering

RESPONSE TO CONTROL:

- Translation: - could initiate and stop predictably - didn't like rate for the input - was really low.

- Attitude: - initial response O.K. - afterwards attitude moved without input for about 3 seconds.

- Height: - good, no problem.

- Precision vs. Gross Maneuvering: - starting, stopping no problem, could hold position easily - bit of drift, easily corrected.

- Forces, Displacements: - comfortable except for steady translation - had to hold large forces.

- Special Control Techniques: - none in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:

- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/2	.15/.75/A	5/5	218H	

RESPONSE TO CONTROL:

- Translation: - predictability reasonably good - problems were stopping and the hover.

- Attitude: - initial response predictability reasonable - did some things afterward in translation and hover, maybe turbulence.

- Height: - no problem.

- Precision vs. Gross Maneuvering: - problems were in tail end of gross acquisition and in hover.

- Forces, Displacements: - fairly comfortable - may have been some tendency to have to modulate steady state and initial forces for translation. Harmony O.K.

- Special Control Techniques: - none in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - adequate at best - aircraft tended to drift, dance around.

- Landing: - adequate performance - had to work reasonably hard to maintain position in hover.

TURBULENCE EFFECTS: - significant - caused me to dance around.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/1.5/2.5	.15/.75/A	5/4	219A	Pitch and roll authority limited

RESPONSE TO CONTROL:

- Translation: - could get reasonable rate going, but required additional input to maintain.
- Attitude: - good initially, predictable, but danced when trying to stabilize.
- Height: - no problem.
- Precision vs. Gross Maneuvering: - starting O.K., stopping not predictable.
- Forces, Displacements: - comfortable but more input required to keep response going.
- Special Control Techniques: - none that worked.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - no better than adequate performance, workload pretty high.
- Landing: - got desired performance, had to work pretty hard at it.

TURBULENCE EFFECTS: - noticeable, wind direction and intensity is varying.

GENERAL: - thought aircraft went open loop at one point, large uncommanded roll excursions.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
9/3/2.5	.15/.75/A	7/6	219B	Pitch and roll authority limited

RESPONSE TO CONTROL:

- Translation: - had trouble initiating - tended to get too much - large inputs required to stop.
- Attitude: - initial response sluggish - then got uncommanded pitch and roll.
- Height: - no problem.
- Precision vs. Gross Maneuvering: - primary problem in gross maneuvering.
- Forces, Displacements: - comfortable but at times, no response to inputs, had to use large inputs - harmony felt like less responsive in roll than pitch.
- Special Control Techniques: - couldn't find any that worked very well.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - performance bordered on adequate, workload pretty darn high.
- Landing: - adequate performance, had to work to prevent large errors.

TURBULENCE EFFECTS: - definitely there - aircraft moved around a fair bit - quite a bit of drift.

GENERAL: (Objectionable features: - uncommanded pitch and roll).

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
12/2/2.5	.15/.75/A	4/3	219C	Pitch and roll authority limited

RESPONSE TO CONTROL:

- Translation: - predictability good.

- Attitude: - always knew what airplane was going to do, predictability good.

- Height: - no problem.

- Precision vs. Gross Maneuvering: - both equally easy, could get good rate going and stop aggressively, could hover pretty well.

- Forces, Displacements: - forces, displacements comfortable harmony good.

- Special Control Techniques: - didn't need any with this airplane.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: - had to work hard due to ambient turbulence.

- Landing: - finding attitude to hover in wind only real problem.

TURBULENCE EFFECTS: - felt gustiness in aircraft. Winds variable, getting side velocities every so often.

GENERAL: - predictable, comfortable overall.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/3	.15/.75/A	10/10	219D	Pitch and roll authority limited

RESPONSE TO CONTROL:

- Translation: Uncontrollable.
- Attitude:
- Height:
- Precision vs. Gross Maneuvering:
- Forces, Displacements:
- Special Control Techniques:

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:
- Landing:

TURBULENCE EFFECTS:

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/1.5/2	.15/.75/A	4.5/4	220A	

RESPONSE TO CONTROL:

- Translation: Got things going pretty well the way I wanted to, trouble stopping on target, tendency to drift out of position.

- Attitude: Predictability pretty good, little bit abrupt, felt there was some bleeding off.

- Height: No problem.

- Precision vs. Gross Maneuvering: Problems primarily at end of gross acquisition and in hover.

- Forces, Displacements: Comfortable, both axes - no difference initial versus final.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Adequate performance, bordering on desired - workload between moderate and considerable.

- Landing: No trouble holding in box - little bit easier (than X-Y-Z tracking).

TURBULENCE EFFECTS: Weren't very noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4/1.5/3	.15/.75/A	6/4	220B	

RESPONSE TO CONTROL:

- Translation: Wasn't getting the rate for the closure needed.

- Attitude: Felt soft at first, little bit laggy – as evaluation proceeded, bothered me less and less – might have been contrast between first and second configuration.

- Height: Good.

- Precision vs. Gross Maneuvering: Primary problems in gross acquisition – Trouble predicting steady rates – stopping on target no worse than first configuration.

- Forces, Displacements: Displacements large – forces, large initial, final larger.

- Special Control Techniques: None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired good part of the time, few times only adequate, then workload got pretty high – adequate performance required extemsove compensation.

- Landing: Significantly easier (than X-Y-Z tracking).

TURBULENCE EFFECTS: Noticeable, airplane dancing around.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/2	.15/.75/A	3/3	220C	Syn. turb. = 0

RESPONSE TO CONTROL:

- Translation:
  Initial lag but not too bad - no trouble setting up rate - could stop it pretty well.

- Attitude:
  Initial a little bit sluggish, liked it general, attitude bled off in steady state.

- Height:
  No problem.

- Precision vs. Gross Maneuvering:
  Not a whole lot of difference - slight tendency to drift from target - could do pretty good job of stopping it and holding it in hover.

- Forces, Displacements:
  Comfortable, both directions, initial and final.

- Special Control Techniques:
  None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:
  Got desired performance, workload no more than moderate - satisfactory without improvement.

- Landing:
  Desired performance, didn't have to work too hard.

TURBULENCE EFFECTS:

Not noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/2/2	.15/.75/A	5.5/4	220D	

RESPONSE TO CONTROL:

- Translation:

  Not too bad – at times, response didn't seem to correspond to inputs – not sure if due to turbulence.

- Attitude:

  Predictability not so great – at times didn't feel tied into the airplane.

- Height:
  Good.

- Precision vs. Gross Maneuvering:
  At times, felt I couldn't modulate my steady state translation, especially for larger inputs – hover, airplane tended to move around without inputs.

- Forces, Displacements:
  Not objectionable – at times, when translating quickly, forces and displacements got up – in general, didn't seem too bad – harmony all right.

- Special Control Techniques:
  Keep the stick moving.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:
  No better than adequate performance – workload pretty high because of stick activity, primarily because airplane moved around without inputs.

- Landing:
  Got desired performance but had to work pretty hard because of tendency to bounce around – didn't seem like turbulence – think it was a combination of airplane and turbulence.

TURBULENCE EFFECTS:

GENERAL: Couldn't really pull them out separately – think it was a combination of airplane and turbulence.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/1.5/2.5	.15/.75/A	5/4	221A	Limited pitch control authority

RESPONSE TO CONTROL:

- Translation:
  Fairly good for gross acquisition — could get rate started pretty well but had trouble stopping it — tendency to slide around a bit — gave me some trouble in hover.

- Attitude:
  Predictability reasonably good — tendency to bleed off but it didn't bother me.

- Height:
  Good.

- Precision vs. Gross Maneuvering:
  Problems were primarily in tail end of gross acquisition and in the hover if errors built up — at times had trouble getting correction going.

- Forces, Displacements:
  Reasonable most of time — at times, thought lateral forces got a little bit high — may have been some disharmony.

- Special Control Techniques:
  None in particular — tried to slow down rate of closure in close.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Desired performance a good part of the time — at times only adequate and had to work reasonably hard — distraction of altitude (control) occasionally led to bigger build-ups in X-Y.

- Landing:
  Once in the box, was able to hold it if errors kept small — no trouble, got desired performance with relatively little workload.

TURBULENCE EFFECTS: Not really noticeable.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
9/3/2.5	.15/.75/A	8/6	221B	Limited pitch control authority

RESPONSE TO CONTROL:

- Translation:

  Predictability really poor — trouble initiating — sometimes dead stopped with an input in — sometimes couldn't change direction.

- Attitude:

  Predictability little bit soft — wasn't all that bad.

- Height:

  Held altitude all right — sometimes had trouble getting a vertical rate started — for the first time had predictability problems with vertical rate.

- Precision vs. Gross Maneuvering:

  Had trouble with both but gross acquisition was worst — tended to overcontrol at tail end, had trouble maintaining position in hover.

- Forces, Displacements:

  Both large particularly at certain times depending on where I was, what I was trying to do.

- Special Control Techniques:

  Nothing really worked.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Adequate performance was not attainable with tolerable workload — at times, controllability in question.

- Landing:

  Adequate performance with tolerable pilot workload, required extensive pilot compensation.

TURBULENCE EFFECTS:

Didn't really notice.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
12/2/2.5	.15/.75/A	10/--	221C	Limited pitch control authority

RESPONSE TO CONTROL:

- Translation:
  Pretty good – could get things started – had some trouble stopping.

- Attitude:
  Funny airplane – initially thought it was pretty good – some problem with slipping and sliding – attitude response predictable most of the time except at end.
- Height:
  O.K. this time.

- Precision vs. Gross Maneuvering:
  Problems were making small corrections – tended to drift in and out – don't think it was the turbulence, it was the airplane and me – felt a little abrupt on inputs.

- Forces, Displacements:
  Comfortable most of the time – harmony was O.K..

- Special Control Techniques:
  Clue was not to get too aggressive, otherwise you aggravated the sliding around.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got desired performance most of the time – had to work pretty hard at it – other times only got adequate performance when sliding around.

- Landing:
  Never got to it.

TURBULENCE EFFECTS:

Not really noticeable.

GENERAL:

S.P. comment "at the end we were pitched back and E.P. put in full control forward and we got nothing." Because of this, aircraft not controllable.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/3	.15/.75/A	8/5	221D	Limited pitch control authority

RESPONSE TO CONTROL:

- Translation:

  Changed throughout the flight - maybe a shift in winds - at times could start and stop reasonably well, other times, couldn't make it go.

- Attitude:

  Reasonably predictable most of the time - one time, put in input, nothing happened, put in bigger inputs and airplane did something quite uncomfortable.

- Height:

  O.K.

- Precision vs. Gross Maneuvering:

  When I felt connected gross acquisition was reasonably good - a few times, didn't feel connected to the airplane - biggest problem backing up.

- Forces, Displacements:

  When things O.K. they were reasonable - other times, couldn't make airplane go anywhere - forces and displacements really went up.

- Special Control Techniques:

  None in particular.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: When I felt connected could do reasonably good job, bordering on desired performance - at times, controllability in question.

- Landing:

  With only small corrections to make could get adequate performance.

TURBULENCE EFFECTS:

Not all that noticeable - noticed external turbulence when I turned to get more into the wind.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
5/2.5/2.5	.15/.75/A	5/5	222A	LAMPS pilot

RESPONSE TO CONTROL:

- Translation:
  Slow but controllable – slow rate prevented fine tuning and adjustments – had to lead control system quite a bit.

- Attitude:
  Not uncomfortable – took a long time to get the motion started, and a long time to arrest.

- Height:
  Absolutely no problem.

- Precision vs. Gross Maneuvering:
  Gross maneuvering kind of poor, not disturbed by turbulence – not very responsive – long time to get anywhere – holding it requires concentration.

- Forces, Displacements:
  Not objectionable – displacements not large, were pretty harmonious for gross and precision maneuvering.

- Special Control Techniques:
  Really had to lead the system.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload not that hard – system slow to respond so workload very low. You're not going to take large attitudes aboard the back of a ship – you do everything in small increments.

- Landing:
  Landed in a skid several times, not good.

TURBULENCE EFFECTS:

Couldn't see the turbulence – no seat of the pants cue.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
5/1.5/2.5	.15/.75/A	6/6	222B	LAMPS pilot

RESPONSE TO CONTROL:

- Translation:
  Disharmony between roll and pitch - in roll, could get nice translation with reasonable attitude change - controllable and felt good - in pitch, took excessive attitude, too little translation for the attitude.
- Attitude:
- Height:
  No problem.
- Precision vs. Gross Maneuvering:
  Not significantly different because of the disharmony.
- Forces, Displacements:
  Absolutely no problem - initial vs. final characteristics the same in gross maneuvering or in tine tuning to stay over the pad, you still had this large disharmony.
- Special Control Techniques:
  Didn't have to lead as much as the last one although you did have to lead it a bit - had to work a lot harder in pitch.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Didn't like using that much pitch attitude to make small tracking adjustments especially in the center of the pad.
- Landing:
  Vertical control no problem - all the tasks were controlled by how much pitch you had to use to maintain longitudinal position.

TURBULENCE EFFECTS:

GENERAL:

Good features, roll, lateral translation - objectionable, longitudinal, pitch.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
9/2.5/2.5	.15/.75/A	7/7	222C	LAMPS pilot

RESPONSE TO CONTROL:

- Translation:
  Translation slow, required pilot to lead his inputs quite a bit.

- Attitude:
  Required excessive pitch and roll for translation, pitch and roll both bad.

- Height:
  Little bit slower than before but still no problem.

- Precision vs. Gross Maneuvering:
  No such thing as precision maneuvering with this system — all gross maneuvering, pilot really had to lead his inputs.

- Forces, Displacements:
  Forces and displacements no problem — problem was the attitudes required.

- Special Control Techniques:
  A lot of lead required.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Reluctant to put in those kinds of pitch and roll attitudes at the back of a ship.

- Landing:
  If you could get near the center of the box, the vertical landing was no problem — tracking over the center of the landing area definitely a problem.

TURBULENCE EFFECTS:

Things were jumping around a little bit more than before.

GENERAL:

Objectionable features — excessive pitch and roll attitudes to get an inadequate amount of translation.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
6/1.5/2.5	.15/.75/A	2/2	223A	LAMPS pilot

RESPONSE TO CONTROL:

- Translation:
  Attitude/translation relationship was very good both in lateral and longitudinal.

- Attitude:

  Attitudes were reasonable.

- Height:
  No problem.

- Precision vs. Gross Maneuvering:
  Relatively easy to establish an attitude and rate of translation — Pilot could discern his rate and halt the rate quite predictably.

- Forces, Displacements:
  No problem, nice harmony between pitch and roll -- nice snappy input in both pitch and roll, pitch a little bit slower — no real problem.

- Special Control Techniques:
  None.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:
  X-Y, Y-Z no problem.

- Landing:
  No problem.

TURBULENCE EFFECTS:

Little bit of turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
8/2/2.5	.15/.75/A	5/5	223B	LAMPS pilot

RESPONSE TO CONTROL:

- Translation:

  Precision translation – big problem – forces very light, weight of hand drives you in one direction or another – no discernable neutral position.

- Attitude:

  No particular problem – didn't bother me at all.

- Height:

  No problem.

- Precision vs. Gross Maneuvering:

  Harmony in pitch and roll no problem – reasonable in translational rates and attitudes generated.

- Forces, Displacements:

  Forces very light.

- Special Control Techniques:

  None – just had to be careful finding neutral point for cyclic.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:

- Landing:

TURBULENCE EFFECTS:

Didn't notice on this one.

GENERAL:

Pilot rating mostly because of control forces.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/2/2.5	.15/.75/A	7/7	223C	LAMPS pilot

RESPONSE TO CONTROL:

- Translation:

- Attitude:

- Height:

  No problem.

- Precision vs. Gross Maneuvering:
  Gross difference between the two – could start O.K. but predicting when to input opposite control to stop was really a problem.

- Forces, Displacements:
  Forces much higher – still no real centering cue — Forces too high for vehicle – harmony O.K., both bad.

- Special Control Techniques:
  Had to learn how far in advance of intended point to put in opposite control – never did get that down very well.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Same problem X-Y and Y-Z – trying to figure out when to input opposite control to stabilize without overshooting.

- Landing:

  Vertical portion no problem – only problem was maintaining X-Y position over pad.

TURBULENCE EFFECTS:

Not susceptible to turbulence.

GENERAL:

Good features very stable, immune to turbulence. Objectionable feature – time lag between input and response.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
4.5/2/2.5	.15/.75/A	6/6	224A	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability was fair – a little bit of sliding – X took more force than Y.

- Attitude:
  Could see motions but they weren't bothersome.

- Height: Excellent.

- Precision vs. Gross Maneuvering:
  Both fair – difficult to keep position exactly where I wanted it.

- Forces, Displacements:
  Felt disharmony in X, Y – heavier forces in X – initial and final forces were harmonious.

- Special Control Techniques:
  Had to slow down before I got to the pad – had to use quite a bit of lead into positioning.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Performance and workload moderate – tracking in X-Y fair, most of problem in X – tracking Y-Z a 3-D task, most of effort in controlling X – excellent Z-axis made it tolerable.

- Landing: Fair – couple of times had to stop to reposition.

TURBULENCE EFFECTS: Really moderate

GENERAL: Good feature, Z axis – bad feature, controlling X.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/2.5	.15/.75/A	4/3	224B	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability about the same as before, had to use some lead but initial response was much better.

- Attitude:
  A little snappier but no problem

- Height: Excellent.

- Precision vs. Gross Maneuvering:
  Precision easier than gross because of faster initial response.

- Forces, Displacements:
  O.K. — still feeling a little more force in X than Y, X-Y harmony may be a little off.

- Special Control Techniques:
  Had to slow down before I got to the box, then ease into it because predictability not too good.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload moderate, not too bad — worse in YZ because that's a three-dimensional task.

- Landing:

TURBULENCE EFFECTS:

Noticeable but not as bad as before.

GENERAL:

Good features, Z axis and initial quick response — bad features, lack of good predictability.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
6.5/2.5/2.5	.15/.75/A	7/7	224C	Second pilot

RESPONSE TO CONTROL:

- Translation:

  Predictability quite poor – hard to get started, very hard to stop – took pretty good forces and motions to get a translation going and then stopping was a problem.

- Attitude:

  Not objectionable.

- Height:

  Excellent.

- Precision vs. Gross Maneuvering:

  Precision worse – if you ever got in box, it was just passing through – with no inputs, it stayed fairly stable, if you tried to move, predictability was bad.

- Forces, Displacements:

  Seemed like more than normal forces and displacements – initial vs. final about the same, harmony O.K. – too much force in both directions.

- Special Control Techniques:

  Tried to put in as much lead as I could, was unsuccessful most of time.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload in X-Y and Y-Z was high and unacceptable performance.

- Landing: Got only one successful landing – was unable to control X-Y.

TURBULENCE EFFECTS:

Having so much trouble with the other stuff I didn't notice.

GENERAL:

Good feature, Z-axis – bad features, poor predictability and difficulty starting and stopping.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/2/2.5	.15/.75/A	3/3	225A	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Good, predictable.

- Attitude:
  Good, no abruptness – noticed pitch attitude more than roll, nothing bad.

- Height:
  Excellent.

- Precision vs. Gross Maneuvering:
  Both good.

- Forces, Displacements:
  Force good – initial and final the same – harmony good – felt like I was backing up most of the time – must be a trim problem I've got.

- Special Control Techniques:
  Had to use very little lead to get the performance I wanted.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Minimal workload in all tasks, X-Y, Y-Z and landing.

- Landing:

TURBULENCE EFFECTS:

They were there but controllable.

GENERAL:

Good features, Z axis and predictability – no objectionable features.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
3.5/1.5/2.5	.15/.75/A	4/4	225B	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability good – slow response required excessive motions and forces to get it started.

- Attitude: Good.

- Height: Good.

- Precision vs. Gross Maneuvering:
  Precision maneuvering was good once I realized I had to move the stick so far.

- Forces, Displacements:
  Large displacements to get response – initial and final about the same – harmony looked good.

- Special Control Techniques:
  Once I got used to big displacements, didn't have much trouble with predictability

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:

- Landing:

TURBULENCE EFFECTS:

Not that much of a problem.

GENERAL:

Good features, predictability and Z-axis – objectionable feature, large displacements.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
8/1.5/2.5	.15/.75/A	4/4	225D	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability fair, little abrupt.

- Attitude: Abrupt attitude changes - didn't bother me too much.

- Height: Good.

- Precision vs. Gross Maneuvering:
  About the same - had to work hard but could do the job.

- Forces, Displacements:
  No problem, normal - initial vs. final the same - harmony all right.

- Special Control Techniques:
  Didn't have to lead all that much but worked pretty hard to get job done.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload moderate with X-Y, Y-Z and landing.

- Landing:

TURBULENCE EFFECTS:

Seemed to have bigger effect - could feel it considerably.

GENERAL:

Good feature, Z-axis - bad feature, little bit unpredictable.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
9/2.5/2.5	.15/.75/A	5/4	225C	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability much worse in X than Y - didn't notice any abruptness but saw some pretty big attitude changes - think we had a slight tailwind - had hard time with small motions in close.

- Attitude:

- Height: Good.

- Precision vs. Gross Maneuvering:
  Precision X maneuvering was difficult, slow response - drifts off in position.

- Forces, Displacements:
  Had to use a lot of X-displacement, initial vs. final no problem.

- Special Control Techniques:
  Had to lead tracking quite a bit.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z:

- Landing:
  Oddly enough, landing task went much better.

TURBULENCE EFFECTS: Felt turbulence.

GENERAL:

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
2.5/1.5/2.5	.15/.75/A	7/7	226A	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability very poor – difficult to predict stopping.

- Attitude:
  Attitude changes pretty large.

- Height: Very good.

- Precision vs. Gross Maneuvering:
  Both about the same – if you didn't have to move it was O.K. – pretty poor predictability if you had to move it.

- Forces, Displacements:
  Both quite large, initial and final – harmony equally bad.

- Special Control Techniques:
  Had to lead quite a bit, high forces made that difficult.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload high, X-Y, Y-Z tracking and landing.

- Landing:

TURBULENCE EFFECTS: Could notice it – most trouble with basic translation.

GENERAL:

Objectionable features, heavy forces and poor predictability.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
12/2/2.5	.15/.75/A	5/4	226B	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability not good, little abrupt, good initial attitude response, translation was rather sluggish.

- Attitude:

- Height: Good.

- Precision vs. Gross Maneuvering:
  Both the same – required lot of lead – required one box-worth of lead on large translations.

- Forces, Displacements:
  Good, initial and final, harmony good.

- Special Control Techniques:
  Had to put in a lot of lead on translation.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload moderate in tracking X-Y and Y-Z.

- Landing: Landing task much easier but on a couple of landings, just before touchdown had some drift and had to make corrections; then could see predictability was not good – no problem as long as you don't have to move it.

TURBULENCE EFFECTS:

GENERAL: Good features, Z and initial response, objectionable features were the predictability and the initial response was just a little bit too much.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
4.5/2/2.5	.15/.75/A	4/4	226C	Second pilot

RESPONSE TO CONTROL:

- Translation:
  O.K., had to use a lot of force and displacements, predictability fair.

- Attitude:
  Could see pretty good attitude changes to do the job I wanted, no problem.

- Height: Excellent.

- Precision vs. Gross Maneuvering:
  Predictability was fair.

- Forces, Displacements:
  Both large, initial and final the same, harmony good.

- Special Control Techniques:
  Once I got on to using a lot of control input to get the response I was able to lead adequately and do an adequate job.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Performance moderate in X-Y, Y-Z and landing because of large displacements required.

- Landing:

TURBULENCE EFFECTS: Didn't notice it too much.

GENERAL: Good feature, the Z-axis - objectionable features were the large forces and displacements.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
13/4/2.5	.15/.75/A	7/7	226D	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability poor, abruptness was the problem — translation extremely difficult to stop.

- Attitude:
  I saw the attitudes, but they were not bad.

- Height: Good.

- Precision vs. Gross Maneuvering:
  Could not do the job in either.

- Forces, Displacements:
  Seemed a little high to get the responses I wanted both initial and final — harmony was good.

- Special Control Techniques: Tried flying it open loop, mechanically putting in opposite control to stop — tried easing it in — nothing worked — whenever I had to make precise positioning, just couldn't do it.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload high in all tasks, X-Y, Y-Z and landing.

- Landing:

TURBULENCE EFFECTS: Didn't notice.

GENERAL: X-Y was so difficult, had trouble controlling Z — single axis look at Z was good.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/2.5	.15/.75/A	3/3	227A	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability pretty good, abruptness not a problem – translation was good.

- Attitude: Attitude seemed normal.

- Height: Height control was good.

- Precision vs. Gross Maneuvering:
  Both pretty easy to do.

- Forces, Displacements:
  Forces and displacements looked good – no problem, initial or final or harmony.

- Special Control Techniques:
  None in particular, had to lead slightly – nothing that made large workload.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Got adequate performance, minimal pilot compensation required for desired performance.

- Landing:

TURBULENCE EFFECTS: Could see it but it was easy to correct.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
8/2/2.5	.15/.75/A	5/5	227B	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability poor, took a lot of attitude motion, lot of stick inputs to maintain a position – translation was good but stopping it required significant lead.

- Attitude:

- Height: Good.

- Precision vs. Gross Maneuvering:
  Took an awful lot of lead, even in the precision work.

- Forces, Displacements:
  Looked normal, initial and final O.K., no problem with harmony.

- Special Control Techniques:
  Had to work pretty hard on lead, workload was moderate in all tracking tasks as well as landing.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Controllable, adequate performance required considerable pilot compensation in X-Y, Y-Z, landing.

- Landing:

TURBULENCE EFFECTS: Didn't see that too much – was working pretty hard just to keep it in the center.

GENERAL: Good feature, Z axis – bad feature, poor predictability.

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
4.5/1.5/2.5	.15/.75/A	4/4	227C	Second pilot

RESPONSE TO CONTROL:

- Translation:

  Predictability only fair – response a little abrupt, that's what allowed me to do the job – predictability not that good in translation – had a hard time predicting where it was going to stop – response quick enough that I was able to overcome that.

- Attitude:

- Height: Good.

- Precision vs. Gross Maneuvering:

  Same comments – it was the quick response that was helping me I felt.

- Forces, Displacements:

  Had to use a lot of stick inputs but they weren't abnormal in size – initial and final O.K. – harmony looked good.

- Special Control Techniques:

  Just having to use lead.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload moderate in all tasks.

- Landing:

TURBULENCE EFFECTS:

Effect was there but I was able to control it with the quick stick response.

GENERAL:

Good features, quickness of initial stick response, not translation but attitude, Z-axis – bad feature, poor predictability.

CONTROL SYSTEM		PILOT RATING	FLT. NO.	GENERAL
LONG/LAT	VERT	X-Y-Z TRK/LNDG		
6/1.5/2	.15/.75/A	6/5	227D	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability only fair - seemed harder in X than Y - little more force in X.

- Attitude:
  Little more attitude response than required.

- Height: Good.

- Precision vs. Gross Maneuvering:
  Precision easier than gross - didn't have to predict so much because errors kept smaller.

- Forces, Displacements:
  Noticed bit of disharmony in force X vs. Y.

- Special Control Techniques:
  None in particular, just lead.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload pretty heavy - able to do satisfactory tracking and landings - occasionally it would go completely out of the box on me.

- Landing:

TURBULENCE EFFECTS: Noticed turbulence because I was having to work so hard with my lead in all positioning.

GENERAL:

CONTROL SYSTEM		PILOT RATING		
LONG/LAT	VERT	X-Y-Z TRK/LNDG	FLT. NO.	GENERAL
6/1.5/3	.15/.75/A	6/6	227E	Second pilot

RESPONSE TO CONTROL:

- Translation:
  Predictability poor in both axes – little hard to get started – seemed to take a lot of force – to stop, if stick just neutralized it would skate past about 2 boxes.

- Attitude: Noticed a lot of attitude motion.

- Height: Good.

- Precision vs. Gross Maneuvering:
  Precision – as long as I kept it in close and turned up my gain I could do better in precision than gross maneuvering.

- Forces, Displacements:
  Seemed to take a little heavy force and displacement to get what I wanted in big translational – initial and final the same – harmony was good.

- Special Control Techniques: For big translation, almost had to go open loop and just mechanically put in an opposite and equal stick input to stop – that worked as good as figuring it out.

TASK PERFORMANCE/WORKLOAD:

- X-Y-Z: Workload quite high because of poor predictability – also, up and away attitudes not bad but in close to a boat I'm not sure.

- Landing: Little easier than X-Y, Y-Z

TURBULENCE EFFECTS: Kept me busy staying in box.

GENERAL: Good feature – Z-axis – objectionable features – predictability and big attitude changes.

Appendix III
EQUIPMENT

The major equipment elements used for the Task Va experiment were:

- The X-22A Variable Stability VTOL Research Airplane with its special subsystems.
- The Microwave Landing System.
- The telemetry van and digital data collection system.

With the exception of the Honeywell Precision Ranging System to be described subsequently, all equipment employed in this experiment was the same as that described in Reference 17.

The principal uses of the various research subsystems of the X-22A (Item 1 above) for this particular experiment were as follows:

- Variable Stability System

    a. Artificial feel system characteristics for evaluation pilot.

    b. Actuation of flight control system for in-flight simulation requirements.

- Airborne Analog Computer

    a. Synthesis of flight control systems.

    b. Simulated-aircraft control-response characteristics.

    c. Mechanization of equations to define position of aircraft in space relative to MLS site.

d. Mechanization of filters to blend MLS and aircraft acceleration data for smoothed signals in both flight control and display systems.

- Head-Up Display - (Including NOVA 3-12 Digital Computer)

a. Generation of symbolic flight control task which was performed under VFR conditions in both the horizontal (X-Y) and vertical (Y-Z) planes.

b. Generation of symbolic flight control tasks which were performed under (essentially) IFR conditions during ground simulation using the X-22A airplane.

- Airborne Magnetic Tape Playback Unit

a. Source of time-varying perturbation signals for landing-ship target (in X-Y and Y-Z coordinates) which were tracked during the in-flight experiment.

b. Source of simulated atmospheric turbulence (acting through flight control system).

Analog block diagrams for the flight control system, synthetic turbulence generation, navigation and complementary filter equations are presented as Figures III-1 to III-5 .

The Microwave Landing System

The scanning beam MLS used for the experiment is basically the U.S. Army Tactical Landing System consisting of AN/TRQ-33 Ground Set Equipment and AN/ARQ-31 Airborne Set Equipment.

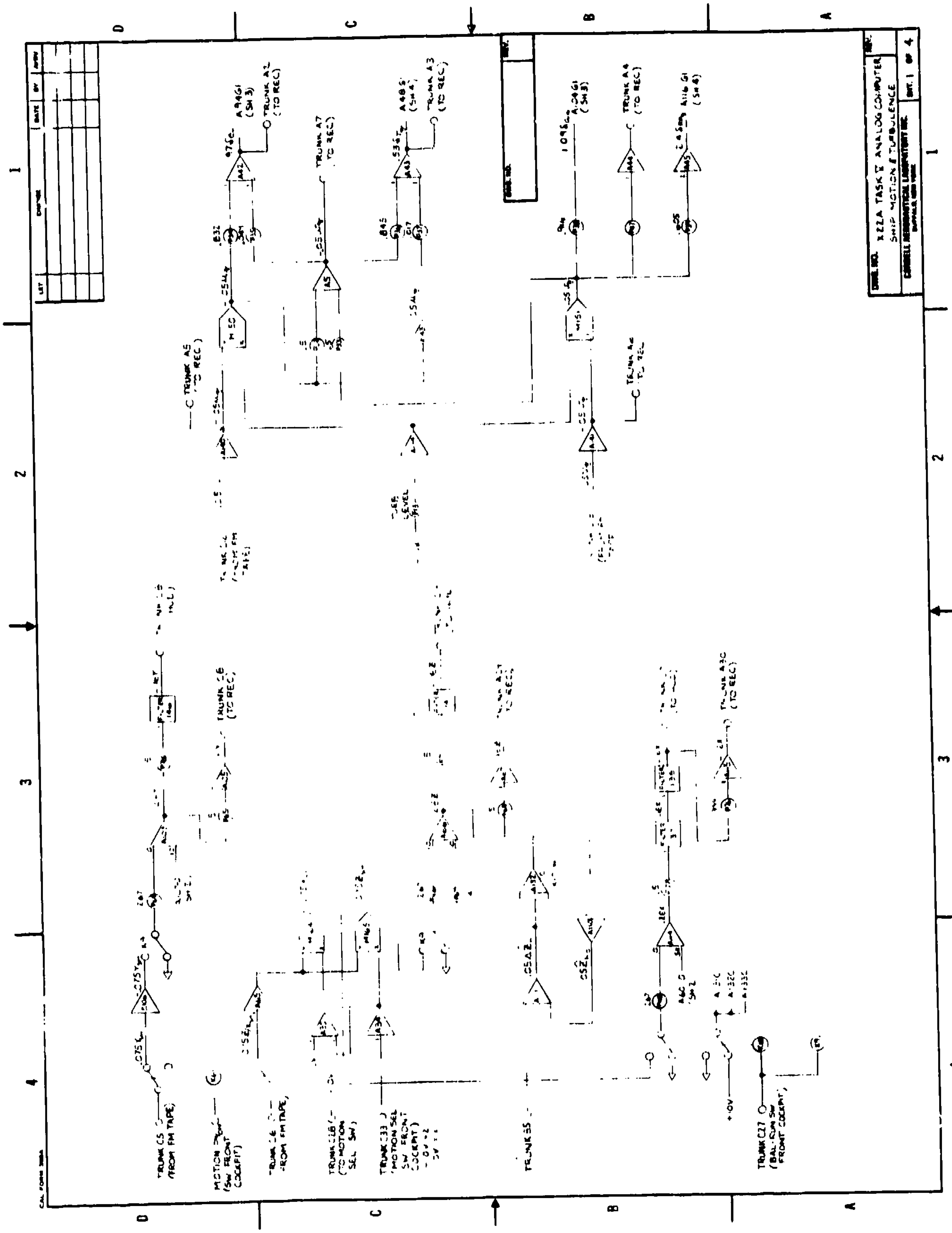


Figure III-1. ANALOG BLOCK DIAGRAM FOR SHIP MOTION AND TURBULENCE

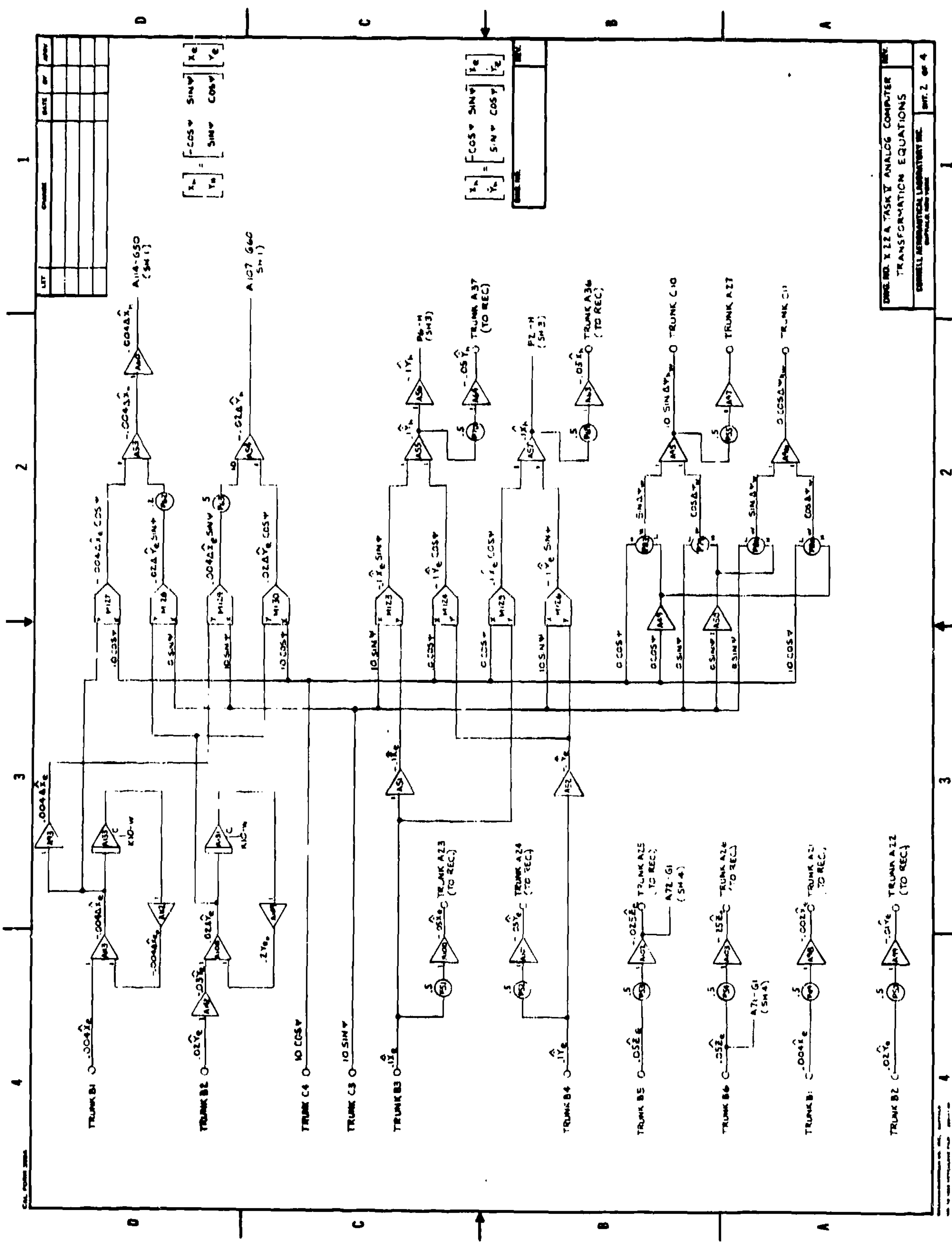


Figure III-2. ANALOG BLOCK DIAGRAM FOR TRANSFORMATION EQUATIONS

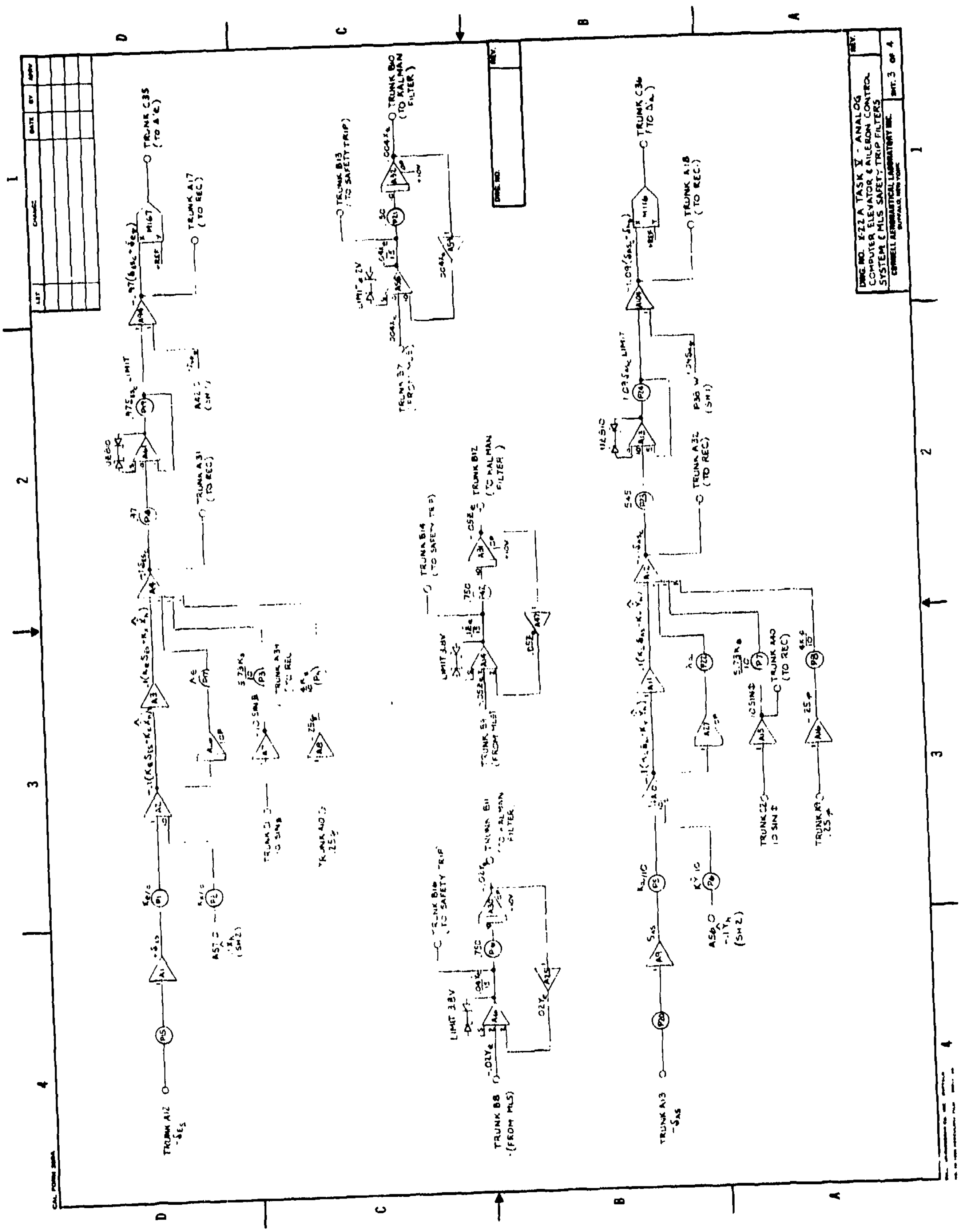


Figure III-3. ANALOG BLOCK DIAGRAM FOR ELEVATOR AND AILERON CONTROL AND MLS SAFETY TRIPS

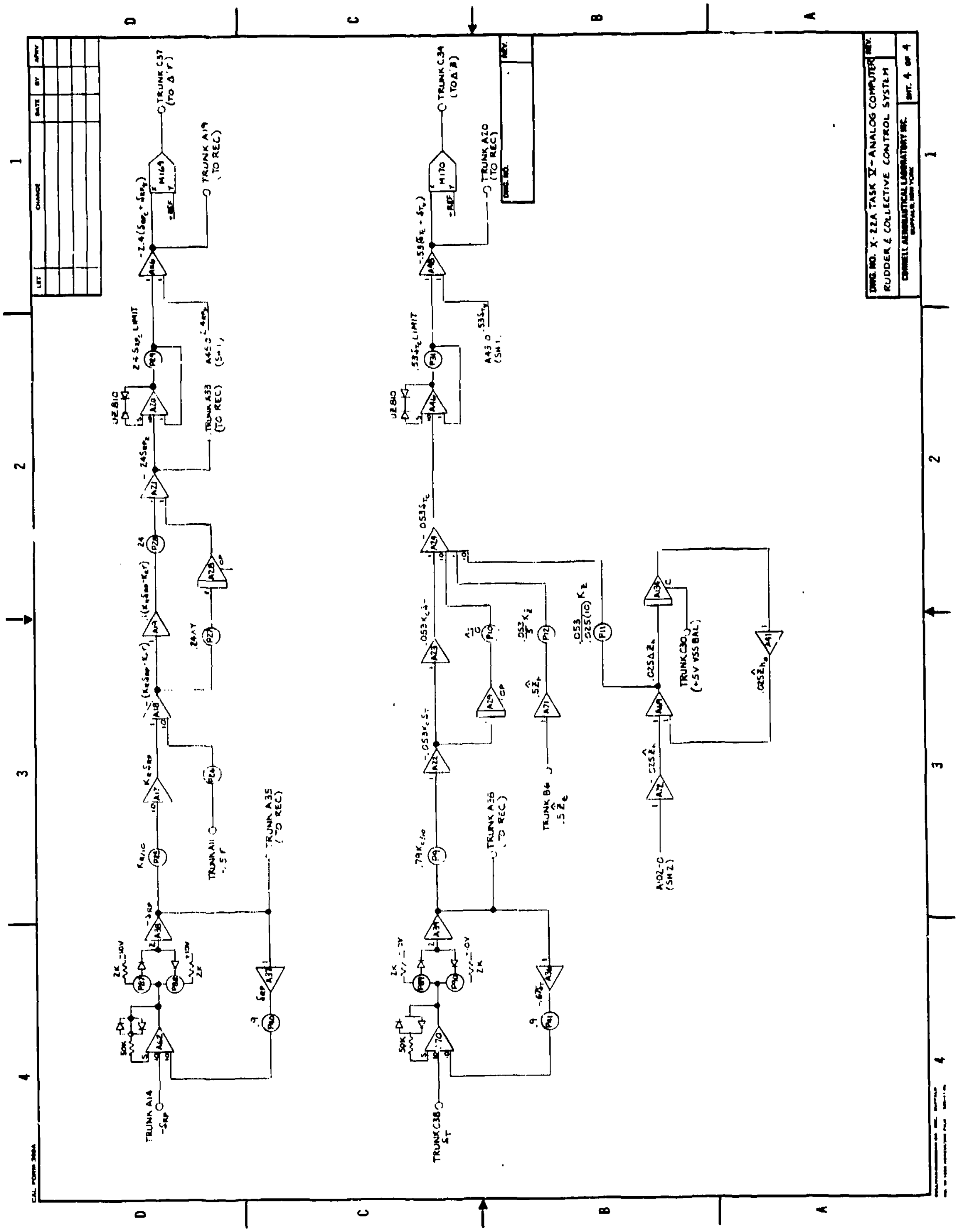


Figure III-4. ANALOG BLOCK DIAGRAM FOR RUDDER AND COLLECTIVE CONTROL SYSTEM

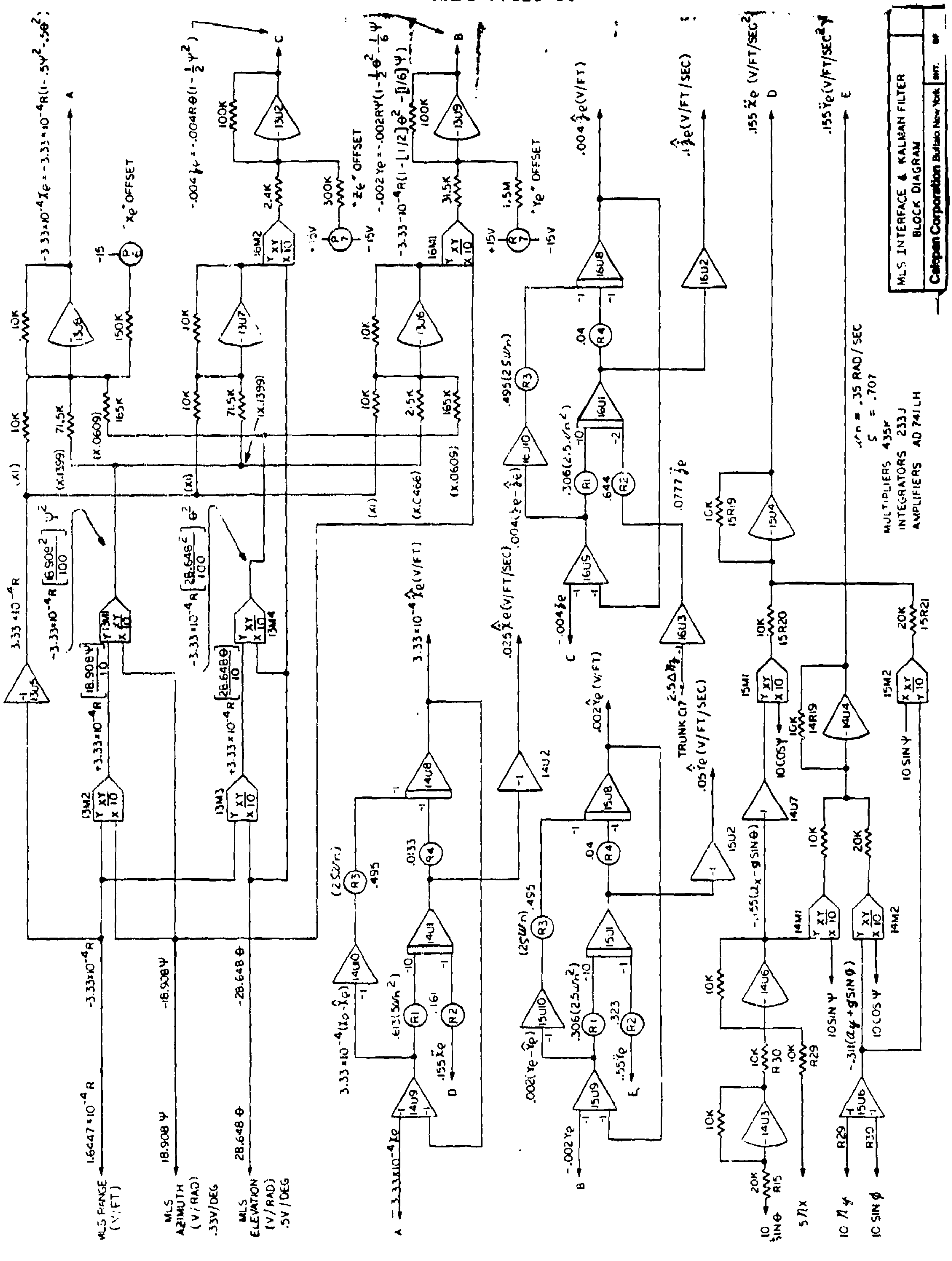


Figure III-5. BLOCK DIAGRAM FOR MLS INTERFACE AND KALMAN FILTER BLOCK DIAGRAM

Two significant alterations have been made to the basic equipment for the particular requirements of X-22A research:

1. The airborne equipment was modified to produce absolute position information in spherical coordinates fixed at the MLS site, i.e. elevation angle (θ_{MLS}), azimuth angle (ψ_{MLS}) and slant range (R_{MLS}). (The basic equipment provides only error information from a fixed localizer and a glide-slope angle which is selectable in flight). This modification was made for the X-22A Task IV Research Program.

2. As part of the Task Va effort, the addition of a prototype Precision Ranging System (PRS) developed by Honeywell and on loan from Honeywell to Calspan. This equipment provides a 2500 feet maximum slant range measurement with a resolution of 3.0 inches (as determined experimentally by Calspan after installation of the PRS on the X-22A). For the Task Va experiment, the PRS range information is used in place of the basic MLS-DME to achieve an overall accuracy on the order of ± one foot in X, Y, Z coordinates defining the aircraft position.

Special Equipment Considerations

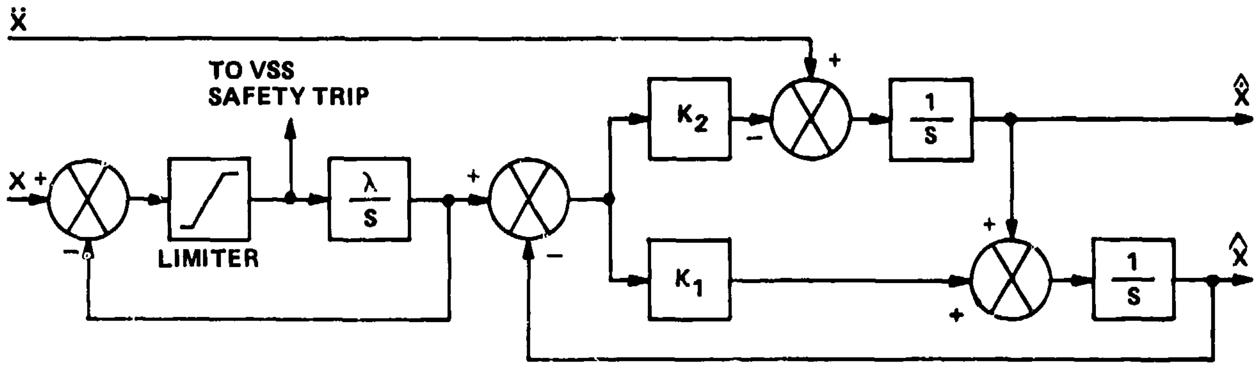
Preparation for Task Va required a major effort and significant accomplishment in developing the schemes and systems to provide aircraft position information with a resolution of at least ± one foot while at the same time insuring "fail-safe" operation upon sudden loss or interruption of any position signal.

The requirement for the high resolution came about from the precision demanded by the control task, i.e. the necessity for the pilot to perceive changes in the position of the aircraft (as displayed on the HUD - and in the real world) as small as one foot.

The uncompensated effects of failures in the aircraft position information, as used in the flight control system, may be (and tend to be) distinctly different from the effects of failures in the other information channels normally used to achieve the simulated aircraft characteristics. Briefly stated, this is because most signals are perturbations about zero or near-zero values whereas the range signal is initially a large value (order of 1000 feet) and, depending on feedback gain requirements, changes on the order of 0.1% of this value may produce significant activity in the flight control system. Even biasing out the initial range value does not prevent sudden loss of range signal from introducing an intolerable transient in the flight control system. Furthermore, Y and Z are approximately the products of absolute range times the MLS azimuth and elevation angles, respectively, so that loss of any MLS signal may produce unacceptable flight control system transients.

To provide positive protection against MLS and PRS failures, the scheme shown in Figure III-6 for the X coordinate was mechanized in the airborne analog computer for all three coordinate measurements. The actual values of the parameters in the protection circuits were determined experimentally by simulating various MLS failures while using the X-22A itself in a ground-simulator mode. Using the aircraft and VSS in this manner eliminated the practically impossible task of modeling all of the mechanical hydraulic and electronic components and systems distributed throughout the aircraft but directly involved in determining the VSS shutdown characteristics. The failure protection circuit adds first order filtering to the position input to the complementary filter. As can be seen by the filter input/output relations, the selection of the filter break frequency at 15 rad/sec results in negligibly small gain and phase errors in the complementary filter output.

Prior to implementation of the MLS Failure Protection circuits, automatic shutdown of the VSS was produced only by any one of the four primary control actuators (pitch, roll, yaw, thrust) reaching a pre-set maximum rate or velocity. Any MLS failure caused the system to shut down in approximately 130 milliseconds. However, the large command signal resulting from the failure produced a significant impulse in the flight control system within the



$$\frac{\hat{X}}{X} = \frac{S^3 + \lambda S^2 + \lambda K_1 S + \lambda K_2}{(S + \lambda)(S^2 + K_1 S + K_2)} = \frac{[.707; .356](14.5)}{[.707; .35]\ (15.0)}$$

$$\frac{\hat{\dot{X}}}{\dot{X}} = \frac{S^3 + (K_1 + \lambda) S^2 + \lambda K_1 S + \lambda K_2}{(S + \lambda)(S^2 + K_1 S + K_2)} = \frac{[.695; .35]\ (15.0)}{[.707; .35]\ (15.0)}$$

Figure III-6 IMPLEMENTATION OF MLS FAILURE PROTECTION CIRCUIT ON INPUT TO COMPLEMENTARY FILTER

130 milliseconds period so that abrupt control stick inputs as much as several inches were observed.

After implementation of the MLS Failure Protection, VSS shutdown during simulated failures was consistently achieved in 25 milliseconds with no detectable transients in the flight controls. The ground simulator results were then verified in extensive ground and taxi tests using all of the actual equipment (aircraft and MLS). Following the ground tests similar results were verified in flight tests.

The following table shows the minimum amplitudes of step changes in position data which were predicted to shut down the VSS safely and the values determined experimentally. The differences are thought to be due to circuit component tolerances and the fact that the test steps were not as mathematically perfect as those applied in the analysis (zero rise time, sharp corners, etc.).

Minimum amplitude of step change in position data required to shut down VSS with no control system transients.

	Predicted	Measured
X	80'	150' to 200'
Y	80'	50' to 100'
Z	35'	50' to 100'

Three other changes made to the equipment to enhance flight safety are the following:

1. Flashing the annunciator panel whenever the radar altimeter descent rate reaches 15 feet per second.

2. Providing the evaluation pilot with a digital readout of radar altitude on the HUD.

3. Flashing the aircraft symbol on the HUD whenever radar altitude is less than 50 feet.

Appendix IV
IDENTIFICATION RESULTS AND SYSTEM CALIBRATION

This appendix describes the methods used to determine the X-22A closed-loop dynamics from flight-measured responses.

At the start of the experiment a mathematical model of the X-22A was available from an earlier flight experiment (Reference 8). This model, employing linear aerodynamics with nonlinear gravitational and kinematic terms, was linearized and served as the nominal model for the purpose of feedback gain selection in this experiment. However, because of the limited quantity of data from which this model was obtained and because inertial velocity feedback had not previously been employed, it was felt that a more thorough modeling effort was required in order to ensure that the closed-loop dynamics for this experiment were accurately known.

System calibration was accomplished with an advanced parameter identification method which determined the parameters of a constant coefficient linear differential equation model which best fit a set of measured closed-loop responses when the aircraft was excited by carefully designed and executed test inputs. The identification method was a batch processing algorithm (Generalized Partitioned Identification Algorithm, SPIA) developed at Calspan (References 13 and 14) which accounts for the effects of random noise on the flight measurements.

Dynamical equations utilized in the identification were of the phase variable (controllable canonical) form. This form facilitated the direct identification of transfer functions since the parameters, p_i, of the identification model are the coefficients of the numerator and denominator polynomials. Theoretically, if the vertical mode is well decoupled, the minimum order of the longitudinal or lateral dynamics is third order. To accommodate potential higher order effects, if required, the model programmed incorporated up to eight measurement equations and ten first-order differential equations. As evidenced by the results, however, a third-order model proved to be sufficient.

A typical set of equations for the identification of the closed-loop pitch/translation dynamics to a pitch stick input is given below.

$$\frac{\dot{x}(s)}{\delta_{es}(s)} = \frac{p_4 + p_5 s + p_6 s^2}{D(s)}$$

$$\frac{\theta(s)}{\delta_{es}(s)} = \frac{p_7 + p_8 s}{D(s)}$$

$$\frac{q(s)}{\delta_{es}(s)} = s\,\frac{\theta(s)}{\delta_e(s)}$$

$$D(s) = p_1 + p_2 s + p_3 s^2 + s^3$$

The complete identification model was considerably more complex and general purpose than the above equations indicate and contained bias parameters in both the state and measurement equations.

System excitation for parameter identification was provided by the X-22A evaluation pilot who was instructed to manually apply two back-to-back doublets with control reversals every four seconds, pause with no input for four seconds and then apply a 10-second step input. A typical pilot input can be seen in Figure IV-1 for the pitch stick and Figure IV-2 for the roll stick input.

Inputs were applied in the pitch and roll axes separately. This procedure allowed separate identification of uncoupled pitch dynamics using a third-order transfer function model and separate identification of roll dynamics as well. The yaw axis was not identified because the heading hold control system mechanized effectively decoupled the yaw degree-of-freedom from the pitch/roll attitude dynamics. Furthermore, the yaw axis dynamics were not a variable in this experiment and were not varied. The vertical degree of freedom was identified separately from the pitch and roll degrees of freedom using a first-order differential equation model relating vertical translational rate to throttle input.

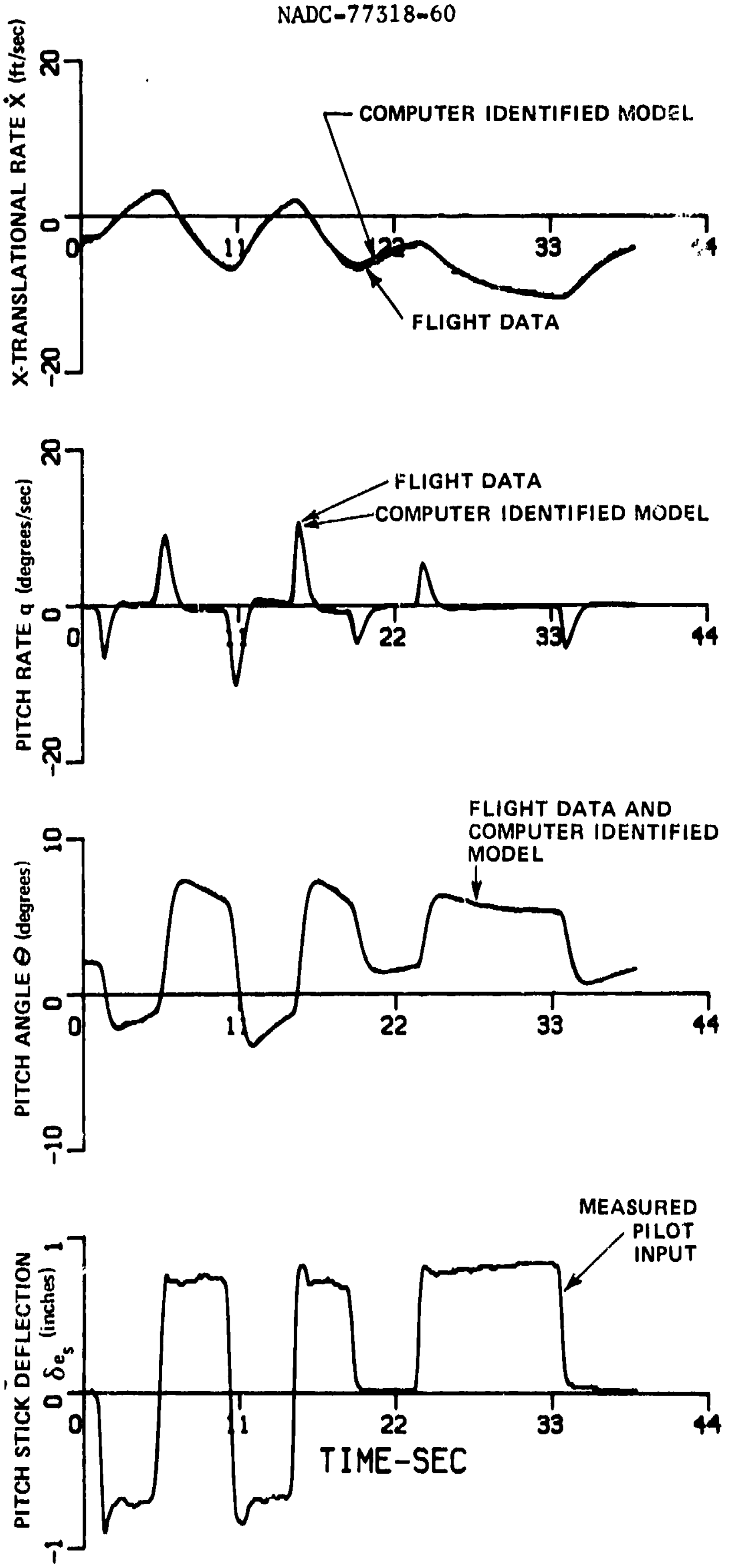


Figure IV-1. OVERPLOTS OF LONGITUDINAL FLIGHT DATA ON COMPUTER IDENTIFIED MATHEMATICAL MODEL RESPONSE TO FLIGHT MEASURED PILOT INPUT — CONFIGURATION 207A (XE56)

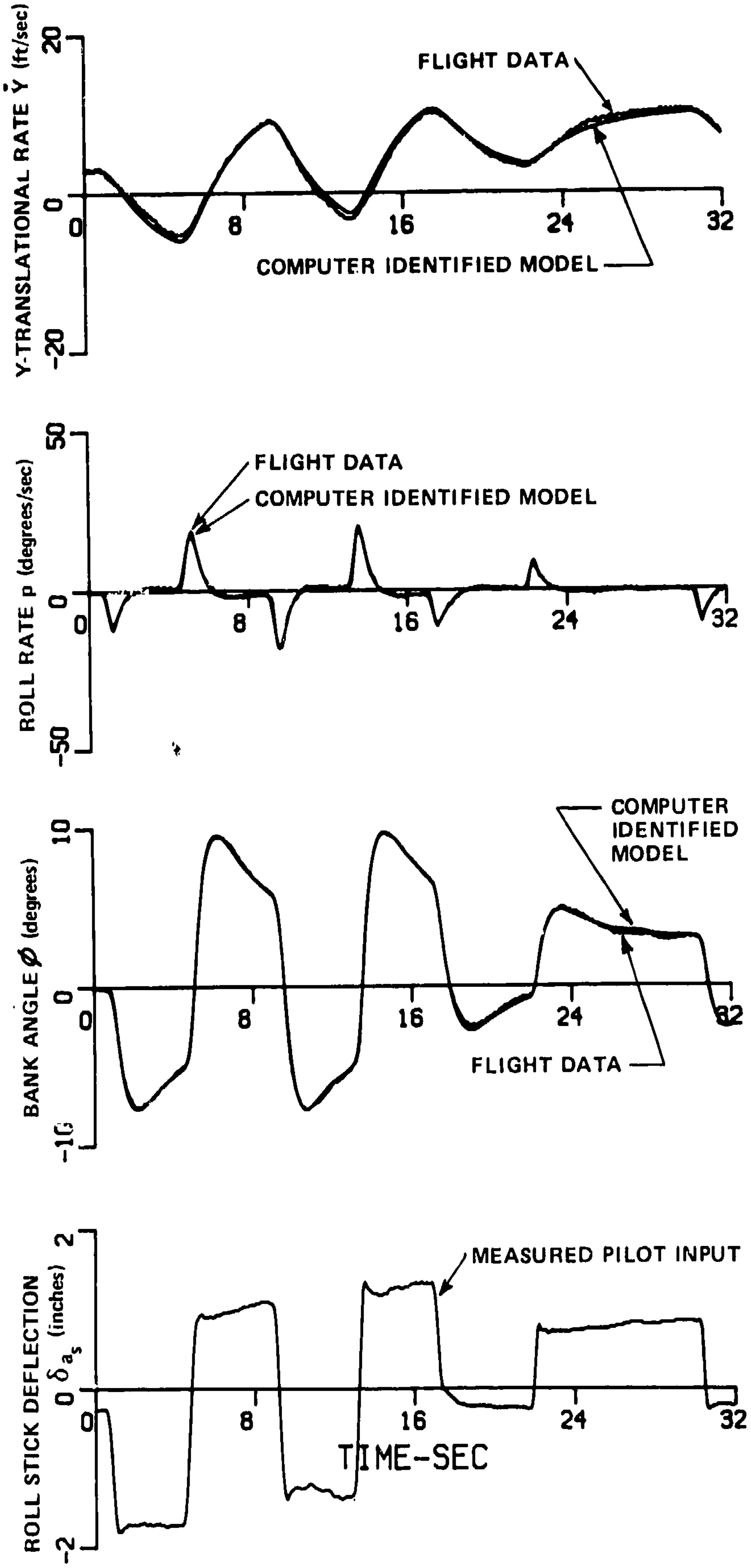


Figure IV-2. OVERPLOTS OF LATERAL-DIRECTIONAL FLIGHT DATA ON COMPUTER IDENTIFIED MATHEMATICAL MODEL RESPONSE TO FLIGHT MEASURED PILOT INPUT — CONFIGURATION 207A (XA51)

Parameter identification was performed using the pilot's stick and throttle displacements as the inputs and the closed-loop vehicle response as the outputs. Thus, the identification results described the X-22A as augmented through its feedback of attitude, angular rates and translational rates.

Identification Results

Twenty-two pitch and roll records were taken for identification purposes. The configurations spanned the entire range of control system dynamics and control sensitivity studied in this experiment. Specifically, the command path gains varied from 3.5 to 13 ft/sec/inch, the path mode time constant, $T_{\dot{x}}$, varied from 1.5 to 4 seconds, and the inner loop attitude system had natural frequencies of 2, 2.5 and 3 rad/sec. The results for the inner-loop attitude system of 2.5 radians per second, the baseline for this experiment, are discussed in this section.

Engineering outputs from the parameter identification algorithm consisted of the following information:

- Identified transfer functions and the resulting pole and zero locations and path mode time constant.

- Overplots of measured and identified model responses forced by the calibration control inputs.

Examples of the latter for pitch and roll stick inputs are shown in Figures IV-1 and IV-2. The excellent quality of the time history matches (the flight data overlays the computer-generated responses) is strong evidence that the model form and parameter values are correct.

To compare the dynamic characteristics actually achieved with the design or nominal parameters, equivalent first order path mode time constants and steady state velocity gains were computed using the identified transfer

function models. This comparison is illustrated in Figures IV-3 and IV-4 for the longitudinal and lateral axes. From these data, it is observed first that there is scatter in the parameters computed from the identified models and second that the achieved velocity gains and path mode time constants are lower than the design or nominal values. Furthermore, the discrepancy is greatest for the lateral parameters. The scatter is thought to be attributable to differences in the hover airspeed between individual calibration records since the X-22A stability derivatives are functions of airspeed.

To smooth the effects of scatter in the identified transfer function models, these data, together with known feedback and command gains were employed to calculate unaugmented stability and control derivatives for each identified configuration. By simple averaging of these identified derivatives, an updated stability and control coefficient model of the X-22A was produced. Figure IV-5 summarizes the data used in these calculations for selected stability and control derivatives. A comparison of the coefficients of the updated and the nominal model are presented in Table IV-1. Differences of significance to the current program are those in the speed stability derivatives (M_u, L_v) and the pitch and roll control sensitivities (M_{δ_e}, L_{δ_a}).

The higher than nominal magnitudes of M_u, L_v are responsible, in part for the higher path mode time constants since inertial and aerodynamic speed stability are additive. As a consequence of the higher control sensitivities, the loop gains for all augmented configurations were larger than those assumed in the design process. The significance of this difference to the augmented dynamics and the flying qualities results of the program is discussed in the body of this report (Section 4.1.1).

Identification of Thrust Dynamics

The vertical dynamics of the unaugmented X-22A were assumed to be modeled by a simple uncoupled differential equation give below.

$$\ddot{z}_e = Z_w \dot{z}_e + Z_{\delta_c} \delta_c$$

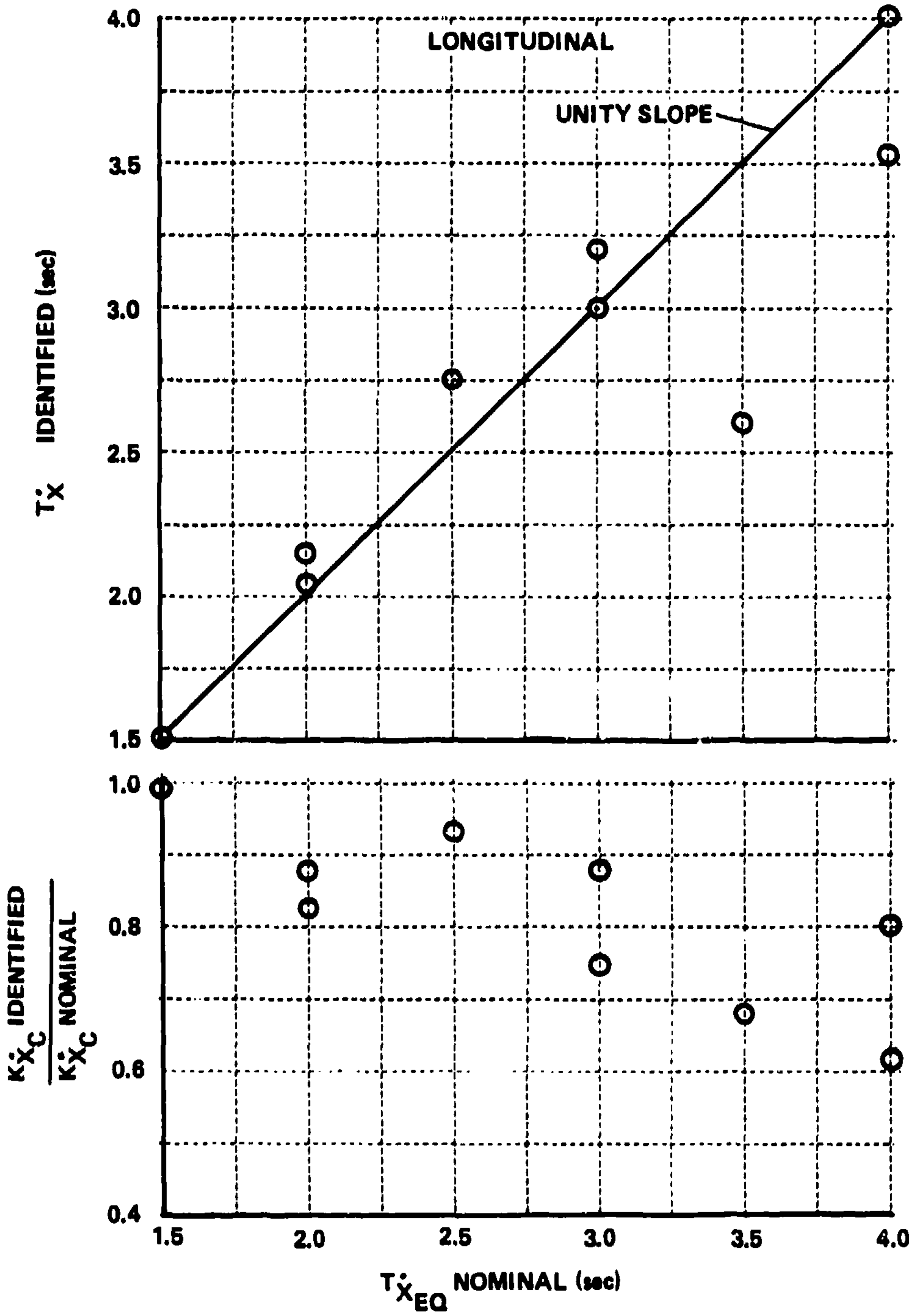


Figure IV-3 COMPARISON OF IDENTIFIED AND NOMINAL LONGITUDINAL TRC PARAMETERS

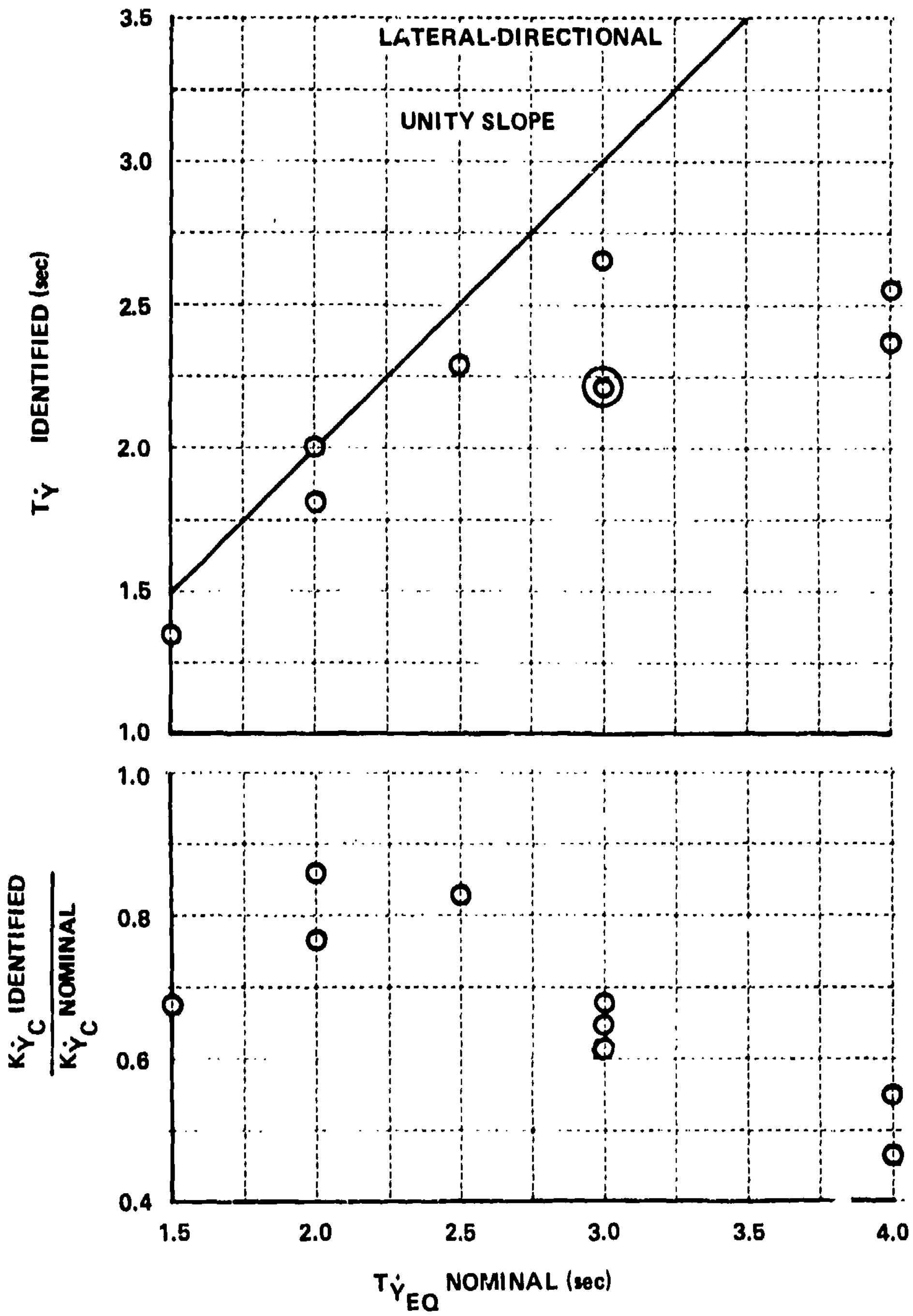


Figure IV-4 COMPARISON OF IDENTIFIED AND NOMINAL LATERAL TRC PARAMETERS

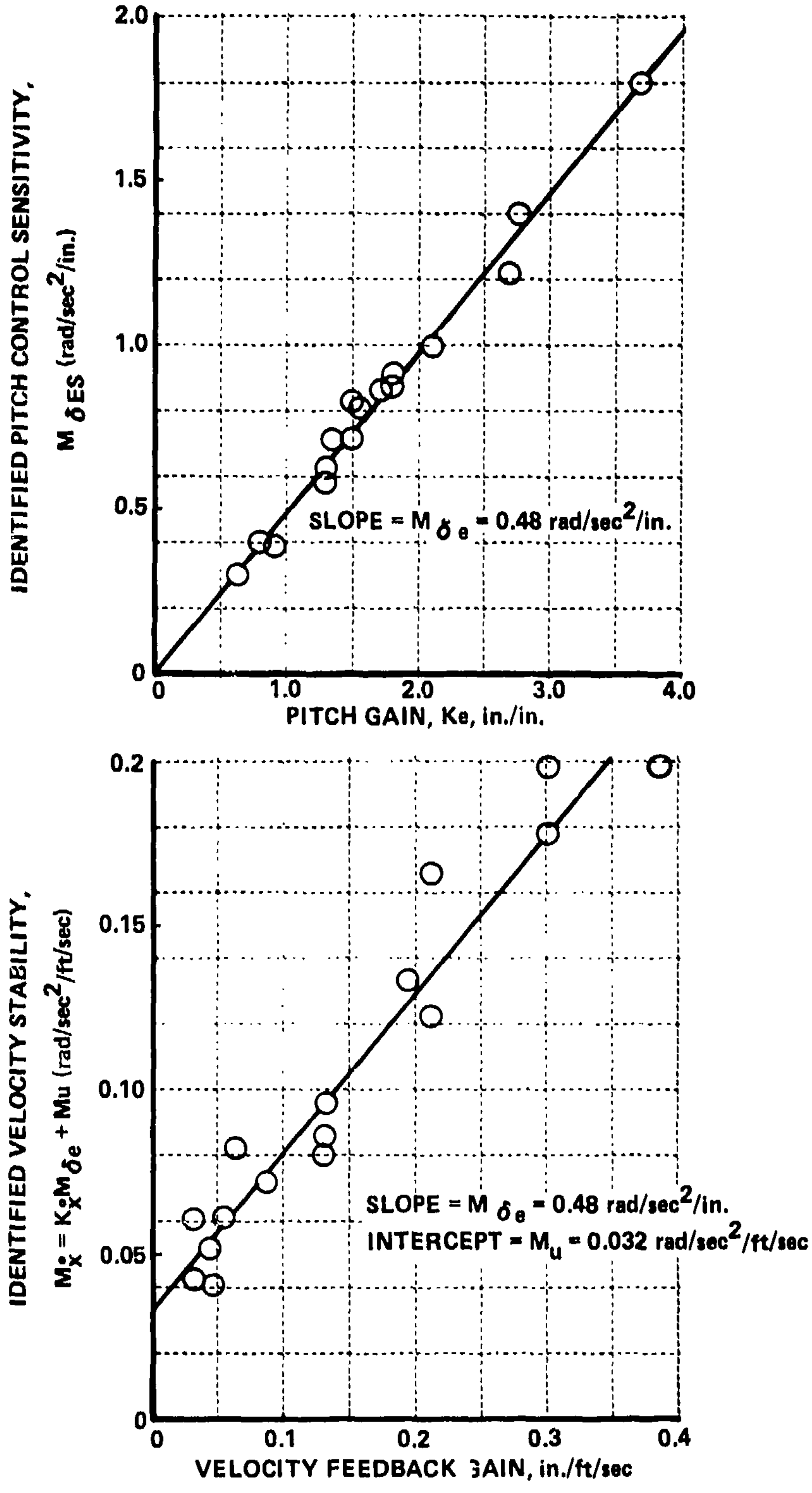


Figure IV-5 EXAMPLE OF ESTIMATION OF X-22A STABILITY AND CONTROL DERIVATIVES FROM IDENTIFIED COEFFICIENTS

TABLE IV-1

COMPARISON OF NOMINAL AND UPDATED

STABILITY AND CONTROL DERIVATIVES

Derivative	Updated Model	Nominal Model
X_u	- .16	- .15
X_q	-3.52	0
X_{δ_e}	0	- .143
M_u	.023	.015
M_q	.2	.23
M_{δ_e}	.479	.348
Y_v	- .175	- .06
Y_p	3.67	-1.67
Y_{δ_a}	0	0
L_v	- .038	- .0148
L_p	- .15	.0698
L_{δ_a}	.588	.38

Units are ft/sec and radians

where $\dot{z}_e$ is the vertical translational rate in an earth axis system and δ_c is the collective input. As described in Section 2.2.3, the vertical augmentation consisted of a first order integral/proportional prefilter together with feedback of altitude and vertical translational rate. Thus the closed-loop transfer function was of the following form:

$$\frac{\dot{z}_e}{\delta_T} = \frac{K_c(s+\lambda_c)Z_c}{s^2-(Z_\omega+Z_{\delta_c}K_{\dot{z}})s-Z_{\delta_c}K_z}$$

where the throttle-collective relationship is given by

$$\delta_c = K_c\frac{(s+\lambda_c)}{s}\delta_T + K_{\dot{z}}\dot{z}_c + K_z z_e$$

This control law was mechanized in either of two ways. In the first case the prefilter time constant and altitude feedback gain were set equal to zero thereby producing the following simplified transfer function

$$\frac{\dot{z}}{\delta_T} = \frac{K_c Z_{\delta_c}}{s-(Z_\omega+Z_{\delta_c}K_{\dot{z}})} = \frac{Z'_{\delta_T}}{s-Z'_\omega}$$

In the second case, the translational rate feedback and altitude feedback were selected to produce two identical real roots, one of which was identically cancelled by the prefilter zero. Thus, the form of the translational rate transfer function remained first order although this second case had the desired feature of altitude hold.

Parameter identification was performed on both types of models using a simple first-order model for the reasons just described. Using measurement noise on the complementary filtered vertical translational rate signal of 0.2 ft/sec produced the results listed in Table IV-2. Overlays of time histories of computed model and aircraft responses to throttle calibration inputs are shown in Figure IV-6. The identification results indicate that the gain through this path is larger while the dynamics of the system are reasonably close to the initial estimates. When these three results are combined using

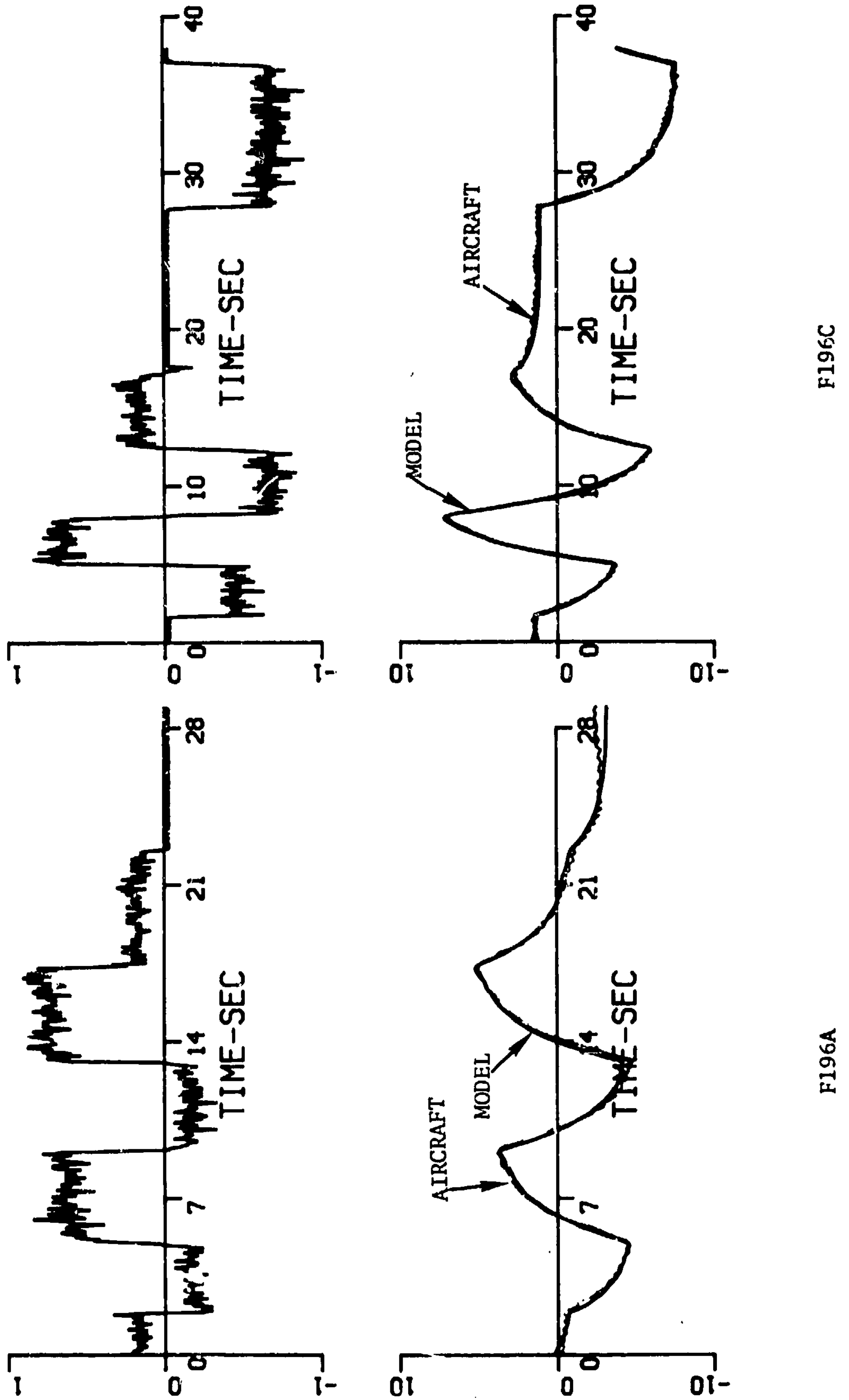


Figure IV-6. TIME HISTORY OVERLAYS FROM IDENTIFICATION OF VERTICAL DYNAMICS

a weighting factor proportional to the accuracy (variance) of each identified parameter, the unaugmented X-22A derivatives can be extracted. These results are shown in Table IV-3.

TABLE IV-2

THRUST AXIS IDENTIFICATION RESULTS

Configuration	Feedback	Nominal		Identified	
		Z'_{δ_T}	Z'_{ω}	Z'_{δ_T}	Z'_{ω}
196A (XT12)	$\dot{z}$	-6.44	-0.5	-7.74	-0.6554
196B (XT13)	$\dot{z}$	-3.22	-0.5	-3.522	-0.4797
196C (XT11)	$\dot{z} + z$	-6.44	-0.5	-7.399	-0.565

TABLE IV-3

UNAUGMENTED X-22A VERTICAL STABILITY AND CONTROL DERIVATIVES

Derivative	Initial Estimate	Updated Estimate
Z_{δ_c}	-1.5	-1.7
Z_{ω}	-0.12	-0.10

The numbers given in the last column of Table IV-3 are recommended for use in all future X-22A hovering experiments.

It is noted that if the updated derivatives in Table IV-3 are used in the altitude hold control mechanization, exact cancelling of the prefilter mode with one of the real roots in the denominator does not take place. The closed-loop dynamics for this configuration are given by:

$$\frac{\dot{z}_e}{\delta_T} = \frac{-7.293\ (s+.5)}{(s+.6816)(s+.4157)}$$

Because of the high damping of this control system, the lack of exact pole-zero cancellation is not significant from a pilot-in-the-loop

control standpoint. The quality of the time history overlays using a first order identification model validates the adequacy of a lower-order control response model.

Identification of LORAS Scale Factor

Early in the data analysis for this program, significant differences were noted between the tail LORAS airspeed measurements and the inertially derived (complementary filtered) translational rate signals. Recall that the heading axis system translational velocities $\hat{\dot{x}}_h$ and $\hat{\dot{y}}_h$ were derived onboard the X-22A by complementary filtering the position information from the MLS with accelerometer data. The tail LORAS, on the other hand, measures the u, v components of airspeed at the tip of the vertical tail. Although airspeed was not employed in this experiment as a feedback variable, it was intended to use airspeed and inertial velocity measurements to estimate ambient winds and turbulence.

In order to cast the problem of calibrating the LORAS with respect to inertial data into a form compatible with parameter identification, the following mathematical model was utilized:

$$\dot{C}(t) = -20\ C(t) + \hat{\dot{x}}$$

$$\hat{u}_T = P_{41}\ C(t) + P_{50}$$

where

$$\hat{\dot{x}} = \hat{\dot{x}}_h - .2705\ q$$

The last equation is necessary to correct the inertial translational rate at center of gravity to the tip of the tail where the LORAS is located. The identification program attempted to find the best values of P_{41}, P_{50} and $C(0)$ so as to minimize the mean squared error between $\hat{u}_T$ and the tail LORAS signal (u_T). In the steady state, the relationship between the inertial data and tail LORAS is given by the following equation: $u_T = s\hat{\dot{x}} + P_{50}$ where $s = \frac{P_{41}}{20}$ is the desired scale factor.

Since the above model assumes that no atmospheric disturbances exist except for steady winds, records taken in calm, ambient conditions were selected. However, several longitudinal identification results were not successful because of turbulence effects. The best results are shown in Table IV-4 for the longitudinal case.

A weighted average also shown in the tables is computed by weighting each estimate in accordance with the accuracy (variance) of the identification of parameter P_{41}.

TABLE IV-4

LONGITUDINAL TAIL LORAS SCALE FACTOR

Configuration	Scale Factor* S
204B (XB31)	1.19
204C (XC32)	1.57
204D (XC33)	1.43
213C (XC85)	1.34
Weighted Average	1.35

$^*u_T(\text{LORAS}) = s\hat{\dot{x}}\ (\text{Inertial}) = s[\hat{\dot{x}}_h(\text{inertial}) - .2705\ q]$

TABLE IV-5

LATERAL TAIL LORAS SCALE FACTOR

Configuration	Scale Factor* S
204A (XB30)	1.58
204B (XB31)	1.86
204C (XB32)	1.81
204D (XB33)	1.76
Weighted Average	1.78

$^*v_T(\text{LORAS}) = s\hat{\dot{y}}(\text{Inertial}) = s[\hat{\dot{y}}_h(\text{inertial}) + .2705\ p]$

Results in Tables IV-4 and IV-5 show that the ratio of LORAS to inertial velocity is 35% in the longitudinal axis and 78% in the lateral axis. These rather sizable scale factors may be the result of

1) Flow blockage caused by the vertical tail (the lateral case only)
2) Flow effects induced by the ducted propellers (longitudinal and lateral).

Earlier calibration of the LORAS performed using an instrumented automobile did not indicate significant scale factors near zero velocity. This method, however, did not duplicate either the flow blockage due to the tail or propeller effects. Furthermore, it was a static calibration in that the automobile was either at constant speed or slowly accelerating. Flight calibrations, however, did indicate significant nonlinearities in the v-LORAS signal, likely due to static pressure differentials at the tip of the tail (Reference 16). The records chosen for LORAS identification, on the other hand, were the same records used for X-22A aerodynamic identification and consisted of either fore-and-aft or side-to-side oscillatory maneuvering with a period of 8 seconds and an amplitude of ±5 ft/sec (approximately).

It is important to note that careful examination of the LORAS signals and inertial measurements showed no perceptible phase lead or lag between the two signals. This determination could be made because the effects of either q or p on u_T or v_T were approximately sharp spikes. The spikes on the LORAS signal agreed nicely with the spikes on the inertial data corrected to the tail location.

The above results suggest that a calibration of the LORAS as installed in the X-22A is required. The results of Tables IV-4 and IV-5 are not recommended as new calibration factors because of 1) the limited sample of data used, and 2) the unresolved scatter in the data. Because of these calibration results, LORAS measurements were not used in the estimation of winds and turbulence. Additional measurements are recommended to calibrate the tail LORAS for future simulation efforts.

Appendix V
MISCELLANEOUS DATA

Table V-1 is a compilation of statistical measures of control utilization during the X-Y-Z tracking and the landing subtasks. For each subtask, the control power measures are: three times the standard deviation and the maximum control defined as the absolute value of the largest command during an evaluation subtask. Control utilization was analyzed separately for each subtask to minimize averaging effects in the standard deviation calculations.

TABLE V-1(a)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

FLT	CONF	TASK	DESC-R/S 3*SIG	DESC-R/S AB(MAX)	DASC-R/S 3*SIG	DASC-R/S AB(MAX)	DTG-G*S 3*SIG	DTG-G*S AB(MAX)
201	A	Y-Z	0.6095	0.5124	1.0396	1.3358	0.1239	0.1363
201	A	LNDG	0.6950	0.8770	0.8968	0.9038	0.1483	0.1622
201	B	X-Y	0.6370	0.5807	1.0349	0.8784	0.1055	0.1164
201	B	Y-Z	0.6736	0.7948	0.8374	1.0459	0.1279	0.1255
201	B	LNDG	0.7745	0.8843	1.1378	1.2421	0.1463	0.1281
201	C	Y-Z	0.6232	0.5664	1.0319	1.4935	0.1627	0.1645
201	C	LNDG	0.6492	0.7580	1.1789	1.3562	0.1861	0.1897
201	D	X-Y	0.6232	0.7265	0.9562	1.0525	0.1090	0.1134
201	D	Y-Z	0.6339	0.7401	0.8730	0.9723	0.1354	0.1309
201	D	LNDG	0.5789	0.5539	0.8626	0.8177	0.1742	0.1385
201	E	Y-Z	0.6400	0.8499	1.0497	1.4558	0.1204	0.1462
201	E	LNDG	0.5881	0.6049	0.8716	0.8349	0.1807	0.1562
201	F	X-Y	0.7103	0.8361	1.0883	1.3609	0.1239	0.1197
201	F	Y-Z	0.6431	0.7006	1.0334	0.8451	0.1413	0.1347
201	F	LNDG	0.5514	0.8645	0.6132	0.5845	0.1379	0.1546
202	A	Y-Z	0.6263	0.9080	1.0928	1.3522	0.1050	0.1461
202	B	X-Y	0.6492	0.8061	0.9695	0.9434	0.1249	0.1495
202	B	Y-Z	0.6416	0.6401	0.8062	1.0112	0.1369	0.1504
202	B	LNDG	0.7072	0.6197	0.9547	0.9254	0.1911	0.2625
202	C	X-Y	0.7072	0.6850	0.9903	0.9167	0.1254	0.1311
202	C	Y-Z	0.6049	0.6448	0.8790	0.8096	0.1189	0.1316
202	C	LNDG	0.6966	0.8918	0.7517	0.6875	0.1229	0.1259
202	D	X-Y	0.5545	0.5610	0.9072	0.9212	0.1098	0.1104
202	D	Y-Z	0.6125	0.6351	0.7943	0.9089	0.1264	0.1239
202	D	LNDG	0.9104	0.8407	1.3556	1.6289	0.1925	0.1924
202	E	Y-Z	0.5927	0.7813	0.9042	1.1320	0.1359	0.1602
202	E	LNDG	1.1258	1.4649	0.9146	0.9428	0.2344	0.2435
202	F	X-Y	0.6125	0.7794	0.8626	1.0834	0.1060	0.1218
202	F	Y-Z	0.6186	0.5959	0.8448	0.9432	0.1269	0.1489
202	F	LNDG	0.5423	0.4780	0.8730	0.8423	0.1264	0.0989

TABLE V-1(b)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

			DESC-R/S		DASC-R/S		DTG-G*S	
FLT	CONF	TASK	3*SIG	AB(MAX)	3*SIG	AB(MAX)	3*SIG	AB(MAX)
203	A	X-Y	0.6446	0.8828	1.0067	1.2149	0.1204	0.1648
203	A	Y-Z	0.6263	0.6431	0.8448	0.8504	0.1364	0.1325
203	A	LNDG	0.6813	0.5852	1.4165	1.6172	0.3150	0.2741
203	B	X-Y	0.5438	0.5148	0.9933	0.8576	0.1219	0.1120
203	B	Y-Z	0.6355	0.6059	0.8968	0.7403	0.1080	0.1078
203	B	LNDG	0.6706	0.7040	1.0230	0.8449	0.2727	0.3029
203	C	X-Y	0.6293	0.8667	1.0334	1.0489	0.1170	0.1144
203	C	Y-Z	0.6629	0.6932	0.9562	1.0937	0.1145	0.1358
203	C	LNDG	0.8264	0.9525	1.2383	1.6292	0.1802	0.1760
203	D	X-Y	0.7149	0.7953	0.9992	1.0244	0.1130	0.1151
203	D	Y-Z	0.6293	0.5983	1.0438	0.9367	0.1189	0.1580
203	D	LNDG	0.9272	1.5837	1.1923	1.4194	0.1518	0.1523
203	E	X-Y	0.6125	0.7098	1.0111	1.0899	0.1209	0.1225
203	E	Y-Z	0.6141	0.5820	1.0200	0.9022	0.1214	0.1077
203	E	LNDG	0.7546	0.7198	0.9592	0.9455	0.1707	0.1406
204	A	X-Y	0.7118	1.1743	1.0408	1.2233	0.1170	0.1404
204	A	Y-Z	0.6309	0.8357	1.1611	1.5035	0.1448	0.2284
204	A	LNDG	0.7928	1.3529	1.2487	1.1959	0.2011	0.2461
204	B	X-Y	0.6721	0.9023	1.0052	1.1937	0.1189	0.1542
204	B	Y-Z	0.6538	0.7578	0.9978	1.0546	0.1274	0.1225
204	B	LNDG	0.8233	0.8561	1.0378	0.9134	0.1413	0.1850
204	C	X-Y	0.6889	0.8426	0.9695	1.2174	0.1180	0.1456
204	C	Y-Z	0.6431	0.7831	0.9205	0.9833	0.1304	0.1562
204	C	LNDG	0.6859	0.5313	0.7988	0.6820	0.1423	0.1206
204	D	X-Y	0.6706	0.7510	1.1596	1.5131	0.1294	0.1537
204	D	Y-Z	0.6660	0.9324	0.9562	1.1612	0.1140	0.1217
204	D	LNDG	0.6018	0.6586	0.9324	0.8538	0.1518	0.1237
205	A	X-Y	0.6645	0.8361	0.9220	1.0643	0.1005	0.1205
205	B	X-Y	0.6324	0.5599	1.1032	1.4040	0.1020	0.1002
205	B	Y-Z	0.6889	0.5188	0.8552	0.8521	0.0916	0.0881
205	B	LNDG	0.9410	1.1333	1.0393	1.2862	0.3210	0.2744

TABLE V-1(c)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

			DESC-R/S		DASC-R/S		DTG-G"S	
FLT	CONF	TASK	3*SIG	AB(MAX)	3*SIG	AB(MAX)	3*SIG	AB(MAX)
206	A	X-Y	0.4033	0.5807	0.9384	1.1978	0.0488	0.0510
206	A	Y-Z	0.4644	0.6334	0.8730	1.0914	0.0737	0.1196
206	A	LNDG	0.5774	0.5751	0.6117	0.7747	0.1005	0.1411
206	B	X-Y	0.7790	1.1738	0.9785	1.0851	0.1120	0.1231
206	B	Y-Z	0.8233	1.1426	1.1418	1.4991	0.1130	0.1493
206	B	LNDG	0.6798	0.7590	1.0364	1.0499	0.1931	0.2295
206	D	X-Y	0.7439	1.0101	1.1685	1.2878	0.1180	0.1345
206	D	Y-Z	0.7195	0.9044	1.1848	1.3939	0.1239	0.1469
206	D	LNDG	0.7225	0.9662	0.9874	0.9285	0.1175	0.1291
207	A	X-Y	0.6721	0.8113	1.0943	1.5013	0.1040	0.1151
207	A	Y-Z	0.7867	1.2789	1.0750	1.2405	0.1194	0.1493
207	A	LNDG	0.6675	0.8984	1.0275	1.4035	0.1692	0.2585
207	B	X-Y	0.6614	0.7076	0.9102	1.0769	0.1005	0.0888
207	B	Y-Z	0.6523	0.5733	1.0571	1.1767	0.1214	0.1232
207	C	X-Y	0.8004	1.0176	1.6035	1.7568	0.1135	0.1572
207	C	Y-Z	0.7531	0.8558	1.1744	1.2055	0.1115	0.1272
207	C	LNDG	0.6889	0.6488	0.8523	0.7369	0.1304	0.1113
207	D	X-Y	0.7164	0.7343	0.9666	1.2165	0.1030	0.1222
207	D	Y-Z	0.6660	0.8206	0.9517	0.9829	0.1085	0.1058
207	D	LNDG	0.7577	1.0081	1.0616	0.9845	0.1309	0.1031
207	E	X-Y	0.7836	1.1007	1.1700	1.3698	0.1120	0.1321
207	E	Y-Z	0.6859	0.7512	1.1106	1.1928	0.1294	0.1197
207	E	LNDG	0.6721	0.5735	0.8805	0.6755	0.1448	0.1206
208	A	X-Y	0.6966	1.0164	0.9502	0.9871	0.1045	0.1129
208	A	Y-Z1	0.6049	0.5617	1.1388	1.1327	0.1110	0.1205
208	A	Y-Z2	0.6492	0.5578	1.0171	1.2401	0.1110	0.1142
208	A	LNDG	0.8814	0.9047	0.8329	0.7679	0.1931	0.2331
208	B	X-Y	0.6996	0.8501	1.0764	1.1539	0.1075	0.1338
208	B	LNDG	0.6385	0.6108	0.9102	1.0075	0.1344	0.1437
208	C	X-Y	0.6889	0.7422	1.0512	1.2599	0.1040	0.1066

TABLE V-1(d)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

FLT	CONF	TASK	DESC-R/S 3*SIG	DESC-R/S AB(MAX)	DASC-R/S 3*SIG	DASC-R/S AB(MAX)	DTG-G"S 3*SIG	DTG-G"S AB(MAX)
209	A	X-Y	0.7240	0.9830	1.1403	1.3229	0.1010	0.1266
209	A	Y-Z	0.7317	0.7145	1.1522	0.9991	0.1314	0.1179
209	A	LNDG	0.6996	0.5066	1.0052	1.1262	0.1244	0.1074
209	B	X-Y	0.7179	0.7853	1.1210	1.2992	0.1135	0.1267
209	B	Y-Z	0.6614	0.5548	0.9859	0.9944	0.1135	0.1224
209	B	LNDG	0.5637	0.4719	0.8612	0.7429	0.1075	0.1068
209	E	X-Y	0.6752	0.7478	1.0275	1.2190	0.1040	0.0898
209	E	Y-Z	0.6477	0.5728	1.1685	1.3581	0.1180	0.1289
209	E	LNDG	0.6721	0.6950	1.2145	1.1054	0.1403	0.1225
211	A	X-Y	0.8906	1.3183	1.6332	1.9054	0.1090	0.1235
211	A	Y-Z	0.8967	0.9805	1.1195	1.3021	0.1613	0.1777
211	A	LNDG	0.8157	0.7063	1.0230	0.8839	0.1289	0.0919
211	B	X-Y	0.7699	0.8945	1.2338	1.5580	0.1045	0.1444
211	B	Y-Z	0.6599	0.9013	1.2116	1.4059	0.1075	0.1329
211	B	LNDG	0.5957	0.5430	0.9102	1.0838	0.1180	0.1288
211	C	X-Y1	1.5107	1.4775	1.9985	2.1749	0.4116	0.5205
211	C	X-Y2	0.9211	1.2764	2.2553	1.6085	0.1065	0.1187
212	D	GREF	1.4053	1.3656	1.0839	1.7134	0.4280	0.4031
212	E	GREF	0.8188	1.1354	1.1002	1.5209	0.1150	0.1239
212	F	GREF	0.9379	1.3195	1.3021	1.8216	0.1219	0.2202
212	G	GREF	0.8890	1.0094	1.4358	1.8085	0.1214	0.3172
213	A	X-Y	0.8065	0.8529	1.2442	1.5906	0.1070	0.1241
213	A	Y-Z	0.7286	0.7918	1.0794	1.2650	0.1165	0.1109
213	A	LNDG	0.7714	0.8224	1.0690	1.1676	0.1214	0.1434
213	B	X-Y	0.7317	0.8984	1.0958	1.1813	0.1030	0.1167
213	B	Y-Z	0.6568	0.6433	1.1254	1.0877	0.1115	0.1148
213	B	LNDG	0.8951	1.1537	1.1388	1.0507	0.3135	0.3398
213	C	X-Y	0.8218	1.0006	1.1626	1.2369	0.1045	0.1143
213	C	Y-Z	0.7515	1.0599	1.4417	1.0705	0.1214	0.1328
213	C	LNDG	0.7347	0.7990	0.9874	0.8936	0.1453	0.1978
213	E	GREF	0.9791	1.5629	1.4684	2.2306	0.2707	0.3491

TABLE V-1(e)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

			DESC-R/S		DASC-R/S		DTG-G"S	
FLT	CONF	TASK	3*SIG	AB(MAX)	3*SIG	AB(MAX)	3*SIG	AB(MAX)
214	A	GREF	0.6186	1.1104	1.5041	1.5612	0.0587	0.0769
214	C	GREF	1.4878	1.6259	2.3474	2.3174	0.4260	0.4439
214	H	GREF	0.9608	1.7155	1.6614	2.2627	0.1831	0.3582
215	D	X-Y	0.7317	0.9546	1.2398	1.5492	0.1045	0.1773
215	D	Y-Z	0.6309	0.6662	1.0586	1.5008	0.1170	0.1245
215	E	X-Y	0.8356	1.2841	1.4239	1.9997	0.1040	0.1347
215	E	Y-Z	0.7271	0.3572	1.2427	1.4390	0.1065	0.1040
215	E	LNDG	0.9316	1.0331	1.5649	1.4432	0.2668	0.3358
216	A	X-Y	0.7057	0.9159	1.2323	1.2414	0.1224	0.1543
216	A	Y-Z	0.6446	0.6218	1.0542	1.0468	0.1030	0.0952
216	A	LNDG	0.4995	0.4617	0.9161	0.7806	0.1518	0.1549
216	B	X-Y	0.8111	0.9608	1.5738	1.5032	0.1145	0.1304
216	B	Y-Z	0.5798	0.7470	1.1210	1.3565	0.1145	0.1405
216	D	X-Y	0.7867	0.9506	1.1462	1.5872	0.1155	0.1075
216	D	Y-Z	0.7531	0.7151	1.2056	1.1805	0.1344	0.1412
216	D	LNDG	0.6843	0.7687	1.0468	1.0038	0.1199	0.1053
217	B	X-Y	0.6904	1.0407	1.3853	1.8204	0.1045	0.1079
217	B	Y-Z	0.6950	0.6945	1.1655	1.2865	0.0990	0.1000
217	B	LNDG	0.8249	1.1960	0.9874	1.0581	0.1115	0.1477
217	C	X-Y	0.4934	0.6135	0.8211	0.8953	0.0478	0.0605
217	C	Y-Z	0.3941	0.5485	0.5598	0.5932	0.0627	0.0652
217	C	LNDG	0.3788	0.5275	0.5642	0.5429	0.0806	0.1223
217	D	X-Y	0.7543	1.0061	1.1848	1.3712	0.1100	0.1283
217	D	Y-Z	0.6064	0.5090	0.9146	0.9571	0.1568	0.1770
217	D	LNDG	0.5957	0.7532	1.1596	1.1001	0.1060	0.1098
218	E	X-Y	0.7561	1.0084	1.1344	1.5155	0.1085	0.1441
218	E	Y-Z	0.6950	0.8419	1.0735	1.1659	0.1239	0.1629
218	E	LNDG	0.6767	0.6933	0.8998	0.9610	0.1399	0.1308
218	F	X-Y	0.3406	0.5729	0.7112	1.0479	0.0403	0.0905
218	F	Y-Z	0.3345	0.4145	0.5048	0.9414	0.0557	0.0648
218	F	LNDG	0.3437	0.3548	0.4365	0.6861	0.0702	0.0816
218	G	GREF	0.9150	1.7525	1.1076	1.3811	0.3305	0.3872
218	H	X-Y	0.6477	0.6960	1.0824	1.3763	0.1025	0.1215
218	H	Y-Z	0.6339	0.5881	1.0037	1.0505	0.1175	0.1215
218	H	LNDG	0.6171	0.5889	0.8419	0.8364	0.1413	0.1350

TABLE V-1(f)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

			DESC-R/S		DASC-R/S		DTG-G"S	
FLT	CONF	TASK	3*SIG	AB(MAX)	3*SIG	AB(MAX)	3*SIG	AB(MAX)
220	A	X-Y	0.7485	1.1385	1.1759	2.0912	0.1075	0.1271
220	A	Y-Z	0.6400	0.5554	0.9443	1.5325	0.1135	0.1149
220	B	X-Y	0.7409	0.3134	2.5716	3.3287	0.1184	0.2208
220	B	Y-Z	0.7027	0.7606	1.2546	1.3952	0.1025	0.1511
220	B	LNDG	0.7424	0.9410	0.8953	0.6256	0.1384	0.1466
220	C	X-Y	0.4140	0.7121	0.7706	0.8643	0.0363	0.0397
220	C	Y-Z	0.3238	0.3193	1.0958	1.4134	0.0319	0.0382
220	C	LNDG	0.2383	0.2908	0.3430	0.4112	0.0956	0.1014
220	D	X-Y	0.6064	0.5706	0.9116	0.8849	0.0995	0.1200
222	A	X-Y	0.6324	0.5910	1.0779	1.0460	0.1189	0.1340
222	A	Y-Z	0.5835	0.8505	1.0735	1.3988	0.1120	0.1611
222	A	LNDG	0.7118	1.1442	1.1210	1.3423	0.1234	0.1325
222	B	X-Y	0.6752	0.7757	1.0126	1.0873	0.1055	0.1292
222	B	Y-Z	0.5499	0.5405	0.8626	0.9098	0.0970	0.0910
222	B	LNDG	0.7699	1.6377	1.0037	1.0374	0.1453	0.2083
222	C	X-Y	0.5530	0.5906	1.0171	1.0903	0.1180	0.1211
222	C	Y-Z	0.5927	0.5927	1.0646	1.3924	0.1130	0.1658
222	C	LNDG	0.6660	0.6855	0.9874	1.2524	0.1289	0.1467
223	A	X-Y	0.7179	0.7098	1.2769	1.4833	0.1145	0.1150
223	A	Y-Z	0.8096	1.3239	1.7669	2.0668	0.1443	0.1677
223	A	LNDG	0.6416	0.7592	1.0839	1.2714	0.1244	0.1511
223	B	X-Y	0.6568	0.7286	1.2175	1.4952	0.1145	0.1198
223	B	Y-Z	0.6874	0.7526	1.0987	1.4026	0.1394	0.1392
223	B	LNDG	0.5346	0.6405	0.9799	1.2492	0.1045	0.1223
223	C	X-Y	0.6263	0.6141	0.9354	1.0072	0.1194	0.1322
223	C	Y-Z	0.6110	0.7144	1.1433	0.9908	0.1244	0.1410
223	C	LNDG	0.7027	0.8345	0.9354	1.2180	0.1145	0.1105
224	A	X-Y	0.5805	0.8361	0.8760	0.9102	0.0946	0.1065
224	A	Y-Z	0.5805	0.5283	0.9502	0.8067	0.1145	0.1491
224	A	LNDG	0.5957	0.6966	0.7869	0.9047	0.1095	0.1717
224	B	X-Y	0.5957	0.5619	0.8315	1.0685	0.0946	0.1150
224	B	Y-Z	0.6110	0.6889	1.0245	1.1655	0.1194	0.1385
224	B	LNDG	0.5957	0.6787	0.7572	0.8325	0.1194	0.1289
224	C	X-Y	0.5194	0.6660	0.8612	1.0270	0.0946	0.1085
224	C	Y-Z	0.6110	0.3172	0.8909	0.9760	0.0995	0.0829
224	B	LNDG	0.6721	1.2953	0.7424	0.6954	0.1194	0.1822

TABLE V-1(g)

PITCH, ROLL AND THRUST CONTROL UTILIZATION

FOR TRACKING AND LANDING SUBTASKS

FLT	CONF	TASK	DESC-R/S 3*SIG	DESC-R/S AB(MAX)	DASC-R/S 3*SIG	DASC-R/S AB(MAX)	DTG-G"S 3*SIG	DTG-G"S AB(MAX)
225	A	X-Y	0.5682	0.7091	0.8315	0.9329	0.0961	0.0966
225	A	Y-Z	0.5912	0.6470	0.9992	0.8004	0.0966	0.0976
225	A	LNDG	0.5881	0.7858	0.8819	0.7866	0.1453	0.2279
225	B	X-Y	0.6232	0.5546	0.9725	0.9191	0.1120	0.1203
225	B	Y-Z	0.5316	0.5864	0.8122	0.8244	0.1145	0.1061
225	B	LNDG	1.0601	1.1440	1.5957	1.8111	0.2220	0.2668
225	D	X-Y	0.7256	0.9448	1.1537	1.4713	0.1155	0.1303
225	D	Y-Z	0.6981	0.7450	0.8463	0.9592	0.0856	0.0762
225	D	LNDG	0.6889	1.1577	0.9324	0.9140	0.1050	0.1659
225	C	X-Y	0.6599	0.6965	0.9799	1.0006	0.1105	0.1403
225	C	Y-Z	0.5637	0.7575	0.8864	1.0045	0.0921	0.0973
225	C	LNDG	0.4919	0.4357	0.8240	0.9577	0.1030	0.1178
226	A	X-Y	0.5423	0.6089	0.9666	1.0698	0.1010	0.1286
226	A	Y-Z	0.5621	0.5516	0.8567	0.8111	0.1060	0.1049
226	A	LNDG	0.6431	0.8919	0.8493	0.7357	0.1189	0.1441
226	B	X-Y	0.5835	0.7370	1.1418	1.1596	0.1045	0.0956
226	B	Y-Z	0.6614	0.3395	0.7795	0.9972	0.1060	0.1349
226	B	LNDG	0.6813	0.6737	0.9057	1.1104	0.1110	0.1112
226	C	X-Y	0.5560	0.5844	0.9725	1.1998	0.1075	0.1348
226	C	Y-Z	0.5866	0.5800	1.1225	1.2369	0.1040	0.1000
226	C	LNDG	0.6171	0.5897	0.8107	1.0551	0.1040	0.1153
226	D	X-Y	0.6110	0.6703	1.0646	1.1995	0.1145	0.1304
226	D	Y-Z	0.5682	0.6176	0.8240	0.7990	0.1105	0.1001
226	D	LNDG	0.7806	0.8396	1.0720	0.9927	0.2309	0.3339
227	A	X-Y	0.6171	0.5416	0.9948	0.9906	0.1115	0.1140
227	A	Y-Z	0.5728	0.5872	0.9874	0.8191	0.0861	0.0830
227	A	LNDG	0.5377	0.5135	0.7706	0.7626	0.0931	0.0894
227	B	X-Y	0.6263	0.6704	0.9666	1.1771	0.1110	0.1358
227	B	Y-Z	0.4919	0.5415	0.9740	0.7901	0.0901	0.0874
227	B	LNDG	0.5957	0.8173	0.8537	0.7543	0.1120	0.0920
227	C	X-Y	0.5957	0.5391	0.8983	1.1525	0.1095	0.1091
227	C	Y-Z	0.5866	0.5927	1.2769	1.4775	0.1140	0.1146
227	C	LNDG	0.5912	0.6352	0.7825	1.0882	0.2911	0.3394
227	D	X-Y	0.5698	0.7221	1.0824	1.1076	0.1180	0.1241
227	D	Y-Z	0.6156	0.5332	1.0289	1.0538	0.1115	0.1198
227	D	LNDG	0.6003	0.5521	0.8805	1.0159	0.1180	0.1547
227	E	X-Y	0.6752	0.3053	1.0378	1.1700	0.1050	0.1256
227	E	Y-Z	0.6416	0.7913	1.3868	1.3317	0.0901	0.0839
227	E	LNDG	0.7103	0.7985	1.1284	1.1521	0.2573	0.4322

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